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# THE ASTROPHYSICAL JOURNAL

## AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

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*Edited by*

PAUL W. MERRILL
Mount Wilson Observatory of the Carnegie Institution of Washington

HARLOW SHAPLEY
Harvard College Observatory Cambridge, Massachusetts

J. H. MOORE
Lick Observatory University of California

OTTO STRUVE
Yerkes Observatory of the University of Chicago

## NOVEMBER 1943

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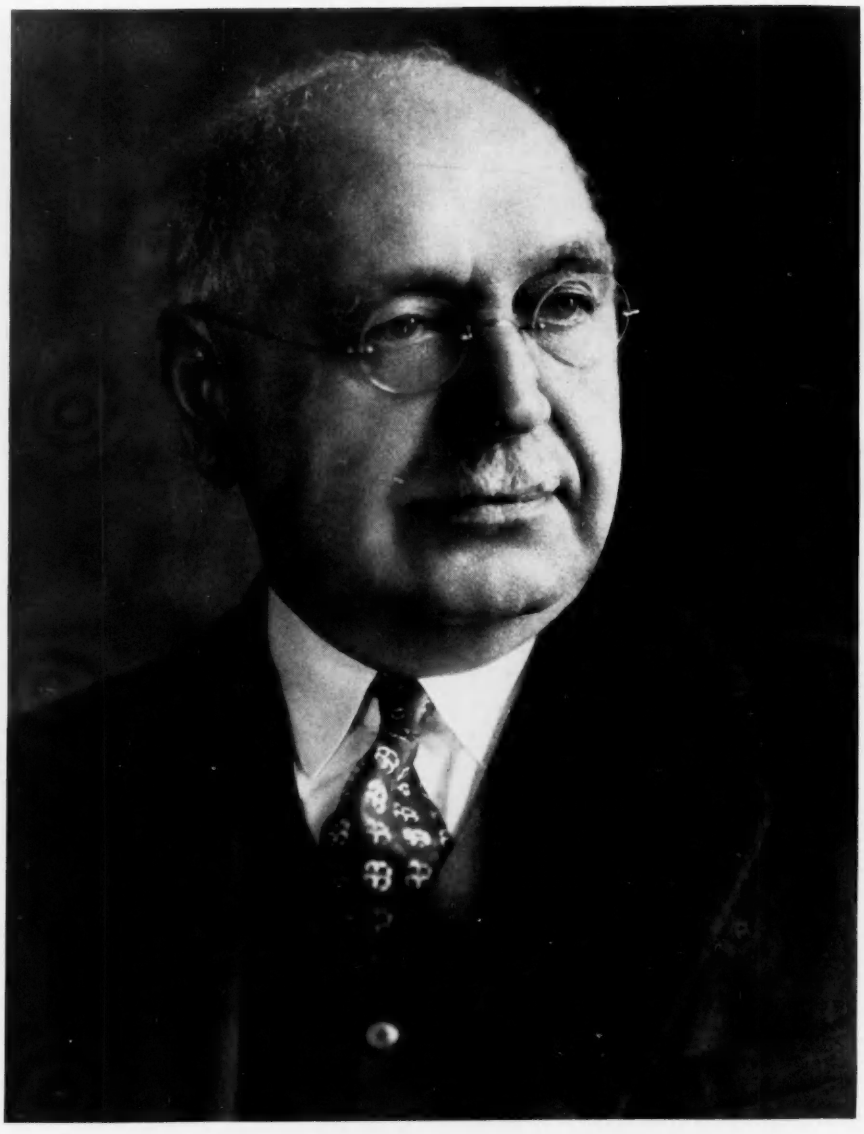

FRANK SCHLESINGER
1871–1943

UNIV. OF MICH.

# THE ASTROPHYSICAL JOURNAL

AN INTERNATIONAL REVIEW OF SPECTROSCOPY AND ASTRONOMICAL PHYSICS

VOLUME 98 NOVEMBER 1943 NUMBER 3


## FRANK SCHLESINGER

1871–1943

In the passing of Professor Frank Schlesinger the world has lost one of its greatest astronomers. From 1932 to 1935 he served as president of the International Astronomical Union, the highest honor that could have been conferred upon him by his peers.

Born in New York City, he received a B.S. degree from the College of the City of New York in 1890. He served as a surveyor for several years, then entered Columbia University and received his Ph.D. in 1898. It was at Columbia that his astronomical work first attracted attention.

The university had received, in 1890, from Lewis Morris Rutherfurd more than a thousand photographic plates of the sun, moon, planets, and stars, taken between 1858 and 1877 with a 13-inch photographic refractor. This gift determined the trend of astronomical research at Columbia for the next decade, during which time Schlesinger was doing graduate work there under John K. Rees and Harold Jacoby.

Schlesinger's thesis for the doctorate, published in 1898, was on *The Measurement of the Rutherfurd Photographs of the Praesepe Group*. This and other papers from Columbia at that time revealed the great possibilities of astronomical photography for precision work. For five years he was in charge of the Ukiah, California, Observatory of the International Latitude Service; then, in 1903, he returned to photographic astrometry at the Yerkes Observatory.

With the rapid development of astronomy, a knowledge of stellar distances became of increasing importance, not only for its intrinsic value in the study of the distribution of the stars in space, but also as fundamental to the solution of many other astronomical problems. Pioneer work in the application of photography to this problem had been done by several persons in this country and abroad.

Schlesinger's experience with the Rutherfurd plates had convinced him that, with a good telescope of great focal length, stellar parallaxes could be determined more economically, more conveniently, and more accurately than by any other method. From 1903 to 1905 he had the opportunity to apply the 40-inch refractor of the Yerkes Observatory to this problem. His classic papers based on this work appeared in the *Astrophysical Journal* in 1910 and 1911. In these he outlined new methods of observation, measurement, and computation. Within the next few years eight observatories had made stellar-parallax determinations either the main feature or a prominent part of their astronomical programs.

Schlesinger left the Yerkes Observatory in 1905 to become director of the new Allegheny Observatory. He planned the main instrument, a 30-inch photographic refractor,

primarily for stellar-parallax work. While awaiting the completion of this telescope, he branched out into other lines, including the determination of radial velocities and the study of spectroscopic binaries. He remained at Allegheny fifteen years.

In 1920 he was called to the directorship of the Yale University Observatory. Here, as at Allegheny, his first task was to plan a new telescope—this time a 26-inch photographic refractor of 36 feet in focal length to be mounted, not in New Haven, but in Johannesburg, South Africa, to carry out for the southern stars a program similar to that at Allegheny for the northern stars. Professor Schlesinger went to Johannesburg in 1924 to supervise the construction of the observatory, the mounting of the telescope, and the inauguration of the research program to be carried out by Dr. H. L. Alden. Up to date more than fifty-thousand plates have been secured at this southern station, nearly all for stellar-parallax determinations. Most of the plates have been sent to New Haven for measurement. About sixteen hundred parallaxes have now been derived.

At Yale, Schlesinger inaugurated another great project: the photographic determination of the positions and proper motions of the stars down to the ninth magnitude that had been observed by meridian circles some seventy years earlier under the auspices of the *Astronomische Gesellschaft*. That meridian-circle work involved the co-operation of a score of observatories over many years. Some years later the *Carte du ciel* was started. This is not yet finished. That, too, was a big co-operative venture, involving the photography of zones by many different observatories. Each plate covered only 4 square degrees, and their quality was not such as to yield results of great precision.

Both at Allegheny and at Yale, Schlesinger experimented with special photographic telescopes designed to give good images over a large field. He finally adopted a Ross lens covering 120 square degrees on a plate 17 × 17 inches. With this one instrument he planned to photograph the northern heavens from New Haven and the southern from Johannesburg. The economy of this procedure is indicated in one of his reports. The total time required to secure the necessary plates for a complete zone 10 degrees wide is about 12 working hours. For one of the 10-degree A.G. zones the time necessary for the visual observations with a meridian circle is about 4700 hours for one man working alone.

Schlesinger also devised a special measuring machine for these large plates and a new technique for deducing the star positions for comparison with the old positions and the derivation of the proper motions. All the plates for this project have been taken and measured. Several quarto volumes of results have been published in the Yale *Transactions*. The work of reduction is still progressing under the direction of Dr. Ida Barney and will probably be completed within 2 or 3 years.

Schlesinger was the author of more than two hundred astronomical papers in scientific journals. While at Allegheny five quarto volumes of the *Publications* appeared under his direction and at Yale twelve volumes of the *Transactions*. Some of his most important papers are in the Introductions to these volumes. At both observatories he was fortunate in having efficient staffs.

At a time when there was almost a stampede of astronomers to the relatively new astrophysics, he devoted his life almost exclusively to astrometry, and to astrometry of the very highest precision. He was concerned not only with the precision of his own observations and reductions but also with that of others. For example, in the introductions to his catalogues of stellar parallaxes in 1924 and 1935 he subjected the results obtained by all the different observatories to a keen analysis and illuminating appraisal.

It is a significant tribute to the value of his work that it has inspired so many others to follow along the same line. Looking back over the last quarter-century of astrometry, he might well have reflected with Aeneas of old:

Quaeque ipse vidi, et quorum pars magna fui.

Many honors were conferred upon him. He was a member of the National Academy of Sciences, the American Academy of Arts and Sciences, the American Philosophical

Society, a foreign associate of the Royal Astronomical Society, honorary member of the Mexican Astronomical Society and of the Italian Society of Spectroscopists, corresponding member of the French Academy of Sciences and of the French Bureau des longitudes, honorary associate of the Royal Astronomical Society of Canada and of the Swedish Academy of Sciences.

He was president of the American Astronomical Society, 1919–22, and president of the International Astronomical Union, 1932–35. He received an honorary Sc.D. from the University of Pittsburgh in 1920 and one from Cambridge University in 1925. He was made an Officer of the Legion of Honor by France in 1935. He was awarded the gold medal of the Royal Astronomical Society, the Valz medal of the French Academy of Sciences, the Bruce gold medal of the Astronomical Society of the Pacific, and the Townshend medal of the College of the City of New York. He was for many years a collaborating editor of this *Journal*.

Those of us who knew him intimately mourn the loss of a dear friend. We think of him as the genial host at New Haven and Lyme and as the presiding genius of the "Neighbors," a group of astronomers whom he used to invite to New Haven several times a year. These meetings were rare experiences: always a social dinner Friday evening, then an opportunity to talk shop Friday night and Saturday forenoon. Whatever the subject of discussion, we were always inspired by his keen insight into all phases of it, his enthusiastic praise of new ideas of which he approved, and his kindly, tactful criticism of those he could not support.

He retired from his position at Yale on July 1, 1941, and was succeeded by Dr. Dirk Brouwer, who had been his chief assistant for many years. In retirement he continued to work on the great photographic star catalogue until his health failed early this year. The end came on July 10.

In 1900 he married Eva Hirsch of Ukiah, California. She died in 1928, and in 1929 he married Mrs. Philip W. Wilcox of New York. He is survived by his widow and by one son by his first marriage, F. Wagner Schlesinger.

FREDERICK SLOCUM

VAN VLECK OBSERVATORY

# SOME COMPARISONS OF SPECTRAL CLASSIFICATIONS*

FREDERICK H. SEARES[1] AND MARY C. JOYNER
Mount Wilson Observatory
*Received May 21, 1943*

ABSTRACT

Regression-difference curves, dependence on magnitude, and average accidental errors in the spectral differences are given for the classification systems of Harvard (HD), Mount Wilson (Adams), Mount Wilson (Humason), Upsala (Petersson), Bergedorf (Schwassmann), and Yerkes (Keenan and Babcock). The mean HD type for MW A stars of a given subtype with n characteristics is later than that for stars of the same subtype with s characteristics. The spectral differences $\overline{\text{HD}} - \text{MW}$ for the n and s groups show opposed and nearly compensating changes with magnitude. The same differences for late-type dwarfs brighter than the sixth magnitude and the series $\overline{\text{Bg}} - \text{MW}$ (Humason) for types earlier than G0 also vary with *m;* otherwise there is little evidence of dependence on magnitude unless the stars are close to the classification limit.

The average accidental errors (0.8 of ME) in the spectral differences vary considerably with the type, conspicuously so for the $\overline{\text{HD}} - \text{MW}$ series (Tables 2, 3, 4), ranging from $\pm 0.7$ classification units for gK0–2 to $\pm 3.3$ units for A5–9 stars. Part of the fluctuations in the average errors is attributable to inequalities in the intervals separating the subtypes used for some of the systems, notably that of the HD.

Freed from statistical errors, the systematic differences in the various series of data ("functional" relation) are usually of the order of 1 unit, although for dK and dM stars the HD classifications are systematically 2–3 units earlier than MW.

## I. INTRODUCTION

The discussion of color index in relation to spectral type given in the following *Contribution* (No. 684) required a preliminary study of the systematic differences between various systems of spectral classification, especially those used for stars near the pole. The results, printed separately in the present paper,[2] include for the spectral differences of each comparison the two regression-curves, the algebraic mean (SD) for successive intervals of magnitude (each subtype separately when the data suffice), and the average error,

$$\text{AE} = 0.8\epsilon = 0.8\sqrt{\epsilon_1^2 + \epsilon_2^2}, \tag{1}$$

where $\epsilon$, $\epsilon_1$, and $\epsilon_2$ are the mean errors of a difference and of the two classifications.

For convenience, "regression-difference" curves rather than regression-curves themselves have usually been tabulated; that is, if $\bar{S}_1$ *vs* $S_2$ represents the regression of $S_1$ on $S_2$, the corresponding regression-difference curve is $\bar{S}_1 - S_2$ *vs* $S_2$. Values for adjacent subtypes have not been combined, even when the groups are small. Smoothed values will, of course, be used in applications to specific problems, but the unmodified differences are retained here because they confirm certain peculiarities in the data, for example, the smoothness of $\overline{\text{HD}} - \text{MW}$ for giant G and K stars (Table 2), in harmony with the small values of AE, or, again, the irregularities in $\overline{\text{Bg}} - \text{MW}_\text{H}$ for A9–F3 stars (Table 6), which indicate the relatively large AE later found in preparing Table 9.

As usual, the regressions arise partly from any real difference in the criteria of classification (or in the application of these criteria) and partly from the lack of balance be-

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 683.

[1] Research Associate, Carnegie Institution of Washington.

[2] For other useful comparisons see A. N. Vyssotsky, *Ap. J.*, **93**, 425, 1941.

tween positive and negative classification errors, which originates in the frequency distribution of the observed spectral types. The significant part played by the frequency distribution is illustrated by Figure 1. Individual spectral differences HD − MW for a few stars have been plotted (ordinates) against the corresponding MW types (abscissae, upper scale). The 45° lines connect points for stars of the same HD type (lower scale). Any MW group—say, G5—thus includes HD classifications ranging from about F8 to K2, and the mean HD will depend on the relative frequency of the subtypes within this interval. Only rarely will $\overline{HD} - MW = 0$ for any MW type, and for the early MW K's the lack of balance will be conspicuous, owing to the low relative frequency of K5 and M stars. For example, there are no HD K2–M stars of MW type K2 to offset the relatively numerous HD G5–K0 stars which have MW type K2, and the difference $\overline{HD} - K2(MW)$ is necessarily negative. The mean error of classification obviously

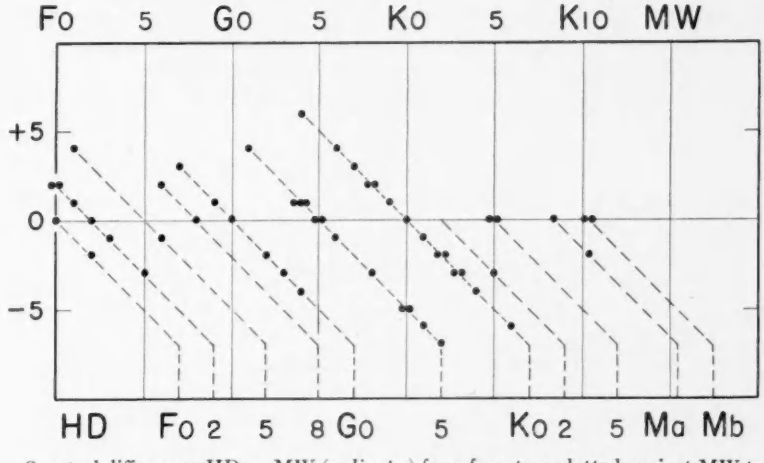


FIG. 1.—Spectral differences HD − MW (*ordinates*) for a few stars plotted against MW types (*upper scale*); to illustrate the influence of the frequency distribution of types on the regression differences $\overline{HD} - MW$. Points corresponding to stars of the same HD type (*lower scale*) are connected by broken lines.

plays an important part, too, since it determines the length of the diagonal lines in the diagram and hence the amount of overlap for types of differing frequency. These statements hold even when the two classification systems are physically identical. Any departure from identity is, of course, added to the statistical effect.

Since type frequency varies with the limiting apparent magnitude, the regressions must also depend on magnitude. For the present data this change does not seem to be large (Tables 5, 7, 8). Judgment is difficult, however, since in some cases the classification may depend on the intensity of the spectral image on the negative and thus be affected by a magnitude error of another kind.

For a representative collection of types completely observed on two systems of classification, the two sets of regression differences may be represented by $\bar{S}_1 - A_2$ and $\bar{S}_2 - A_1$, where the subscripts denote the systems, $S$ the individual types, and $A$ a particular type chosen as a common argument for the grouping of the differences. If the systems are identical, $A_1 = A_2$, physically as well as numerically; and if the mean errors are equal, $\bar{S}_1 - A_2 = \bar{S}_2 - A_1$.

If the systems are not identical, we may eliminate the statistical influences and obtain the functional relationship by evaluating the difference $A_1 - A_2$ for the common argument $A$. We assume the correlation to be linear and consider the two regression

lines and the impartial or functional line lying between them, with the origin at the common intersection (Fig. 2). $A_1$ and $A_2$ will be the co-ordinates of some point on the impartial line. Corresponding to the abscissa $A_1$, the first regression line has the ordinate $\bar{S}_2$; and, corresponding to the ordinate $A_2$, the second regression line has the abscissa $\bar{S}_1$. The slopes of the three lines are $S_2/A_1$ (first), $A_2/A_1$ (impartial), and $A_2/S_1$ (second), where the bars have been omitted. The second slope is the geometric mean of the first and third.[3] Hence $A_2/A_1 = S_2/S_1$, from which

$$(A_1 - A_2)\frac{S_2}{A_2} = S_1 - S_2 . \tag{2}$$

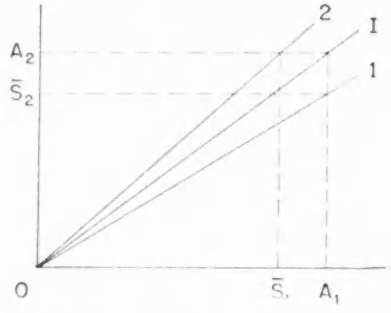


FIG. 2.—Regression lines and impartial line

Now write

$$(\bar{S}_1 - A_2) - (\bar{S}_2 - A_1) = d , \tag{3}$$

whence, again omitting bars,

$$S_1 - S_2 = d - (A_1 - A_2) .$$

Substituting into equation (2), we have

$$(A_1 - A_2)\left(1 - \frac{\delta}{2}\right) = \frac{d}{2} , \qquad \delta = 1 - \frac{S_2}{A_2} . \tag{4}$$

When the correlation coefficient is high, as it is for systems of spectral classification, $\delta$ is a small quantity. Hence the functional difference $A_1 - A_2$ for the common type $A$ is nearly equal to one-half the difference in the regression differences. To the same approximation, $\bar{S}_1 - \bar{S}_2$ also equals $d/2$. Even when the correlation is not linear, equation (4) will give a general idea of the physical relationship of two systems.

Reversion to these rather elementary matters shows, first, the scale of the disturbance produced by accidental errors and, second, the importance of dealing with representative collections of data extending over the entire spectral range. Since the present data do not always satisfy these conditions, one must be on guard against assuming too great a generality in the regressions as tabulated.

The average errors have been found from

$$\mathrm{AE} = \sqrt{\frac{n}{n-1}}\,(\mathrm{AD}) , \tag{5}$$

[3] G. Strömberg, *Mt. W. Contr.*, No. 628; *Ap. J.*, **92**, 156, 1940.

where AD is the arithmetic mean difference found after correction for the algebraic mean, SD. The radical factor, which corrects for sampling error, is unimportant unless $n$, the number of stars in the group, is small.

The errors of classification can be estimated, roughly at least, from the various values of AE. For a closed cycle including an odd number of comparisons, say $S_1 - S_2$, $S_2 - S_3$, $S_3 - S_1$, they can be calculated directly from equations having the form of (1);[4] but, if the cycle number is even, the $2n$ equations are not independent. Even then an approximate solution for the $2n$ unknowns is sometimes possible.[5]

Aside from the *Henry Draper Catalogue* (HD), the following collections of spectra have been used:

| | | | |
|---|---|---|---|
| Mount Wilson, Adams and others[6] | MW | Bergedorf, A. Schwassmann[9] | Bg |
| Mount Wilson, M. L. Humason[7] | $MW_H$ | Yerkes, Keenan and Babcock[10] | Y |
| Upsala, J. H. Petersson[8] | U | | |

The first of these lists is for the sky at large, the second and fourth for the Selected Areas of Kapteyn, and the third and fifth for the polar region north of +80° declination.

Throughout the tabular material the differences and the values of AE are expressed in units of 0.1 of a spectral class. The magnitudes, unless otherwise noted, are on the visual or photovisual system.

## II. MOUNT WILSON (MW) AND HARVARD (HD)

Although the general trend of the $\overline{HD} - MW$ regression is suggested by Figure 1, many more stars must be used to define the systematic relations. Moreover, it is desirable to segregate the stars according to the MW giant and dwarf designations, since differences in the frequency distributions of giants and dwarfs, if nothing else, may appreciably affect the regressions. The results are given in Table 2 and illustrated in Figure 3. The spectral equivalents in Table 1 used in preparing Table 2 are explained later. The 2300-odd stars used for Table 2 comprise all the MW stars occurring in the HD (variables, composite types, etc., omitted), except those of types F0–F9 and of gG4–gK5, of which only 40 per cent were needed; in fact, for the F's, 20 per cent selections would have done nearly as well, since the difference-curves for two such groups are practically identical. This variant in selection has no effect on the $\overline{HD} - MW$ regression but would distort the $\overline{MW} - HD$ curve, were not suitable correction factors applied. To illustrate, suppose that Figure 1 represents a mixed selection such that, relative to the K's, the G's (both MW) are only half as numerous as in a representative collection. Thus for HD K0 each positive difference (on the 45° line) must be used twice in combining it with the negative differences to obtain the correct $\overline{MW} - HD$ for HD K0.

It is to be noted, too, that the MW catalogue includes no B types; the selection of HD early A's is therefore incomplete by an unknown amount. The HD type-frequencies are not normal, and the second regression is distorted. Even the point for A5 is doubtful. In fact, the regression-curves throughout correspond to the particular selection of stars included in the MW list that are bright enough to appear in the *H.D.*, whether representative of the sky at large or not.

[4] Butler and Thackeray (*M.N.*, **100**, 450, 1940) have used this method.

[5] For an analogous problem involving errors in magnitudes see *Magnitudes and Colors of Stars North of +80°, Carnegie Institution of Washington Publications 532*, p. 43, 1941.

[6] *Mt. W. Contr.*, No. 511; *Ap. J.*, **81**, 187, 1935.

[7] *Mt. W. Contr.*, No. 458; *Ap. J.*, **76**, 224, 1932.

[8] *Medd. från Astr. Obs. Upsala*, No. 29, 1929.

[9] *Bergedorfer Spektral-Durchmusterung*, Vols. **1**, **2**, 1935, 1938.

[10] *Ap. J.*, **93**, 64, 1941.

TABLE 1

SPECTRAL EQUIVALENTS

| | HD | $\overline{MW}$ | Equiv. HD | No. Stars |
|---|---|---|---|---|
| Giants | Ma | K 8.4 | K7.7 | 148 |
| Giants | Mb | K10.4 | K9.7 | 49 |
| Dwarfs | Ma | K 8.4 | K6.1: | 5 |
| Dwarfs | Mb | K10.4 | K7.5: | 1 |

TABLE 2

REGRESSION DIFFERENCES

| Sp | $\overline{HD}-MW$ | | | | | | $\overline{MW}-HD$ | | | | | | $\overline{HD}-MW_H$ | | $\overline{MW}_H-HD$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Main Seq. | | | Giants | | | Main Seq. | | | Giants | | | | | | |
| | SD | AE | No. | SD | AE | No. | SD | AE | No. | SD | AE | No. | SD | No. | SD | No. |
| B4 | | | | | | | | | | | | | +2.5 | 2 | | |
| 5 | | | | | | | | | | | | | | | −1 | 1 |
| 8 | | | | | | | | | | | | | +1.8 | 4 | −2.0 | 2 |
| 9 | | | | | | | | | | | | | +1.0 | 2 | +0.5 | 2 |
| A0 | −1.5 | | 2 | | | | | | | | | | +0.2 | 21 | +0.5 | 33 |
| 1 | −0.3 | | 17 | | | | | | | | | | −0.6 | 7 | | |
| 2 | 0.0 | | 40 | | | | | | | | | | −1.4 | 7 | +0.9 | 15 |
| 3 | +0.1 | | 39 | | | | | | | | | | −1.7 | 3 | +1 | 1 |
| 4 | +1.0 | | 43 | | | | | | | | | | −2.5 | 2 | | |
| 5 | +1.7 | | 46 | | | | +0.1 | ±1.8 | 45 | | | | −1.0 | 4 | +4.0 | 5 |
| 6 | −0.5 | | 55 | | | | | | | | | | −0.3 | 6 | | |
| 7 | +0.8 | | 47 | | | | | | | | | | −1.0 | 2 | | |
| 8 | −0.1 | | 44 | | | | | | | | | | +5.5 | 2 | | |
| 9 | −0.2 | | 46 | | | | | | | | | | +1.0 | 2 | | |
| F0 | −0.3 | ±2.8 | 23 | | | | 0.0 | 2.6 | 83 | | | | +0.2 | 6 | −1.6 | 9 |
| 1 | +0.6 | 2.3 | 23 | | | | | | | | | | +9 | 1 | | |
| 2 | +0.9 | 2.4 | 42 | | | | 0.0 | 1.9 | 52 | | | | +1.6 | 5 | −2.7 | 3 |
| 3 | +0.6 | 2.3 | 45 | | | | | | | | | | −0.3 | 3 | | |
| 4 | +0.5 | 2.2 | 52 | | | | | | | | | | +1 | 1 | | |
| 5 | +0.5 | 1.7 | 48 | | | | −0.7 | 1.8 | 137 | | | | +3.0 | 2 | +1.8 | 13 |
| 6 | +1.2 | 2.2 | 31 | | | | | | | | | | +1.0 | 3 | | |
| 7 | +1.0 | 1.5 | 28 | | | | | | | | | | +3 | 1 | | |
| 8 | +0.4 | 1.5 | 32 | | | | −1.2 | 2.2 | 88 | | | | −1.0 | 3 | +0.1 | 14 |
| 9 | +1.2 | 1.4 | 19 | | | | | | | | | | +9.3 | 3 | | |
| G0 | +0.6 | 1.7[s] | 60 | −0.1 | ±2.9 | 15 | +0.4 | 2.4 | 182 | +3.4 | ±2.0 | 38 | −1.1 | 10 | +2.4 | 14 |
| 1 | −0.3 | 2.0 | 51 | +0.6 | 3.1 | 13 | | | | | | | +1.0 | 4 | | |
| 2 | −0.8 | 2.3 | 51 | +1.0 | 3.3 | 23 | | | | | | | +2.7 | 6 | | |
| 3 | +0.5 | 2.8[s] | 39 | +0.8 | 2.8 | 26 | | | | | | | +2.7 | 10 | | |
| 4 | −0.4 | 2.7 | 47 | +1.3 | 1.8 | 29 | | | | | | | +4.8 | 4 | | |
| 5 | −1.0 | 2.0 | 39 | +1.4 | 2.1 | 32 | +0.3 | 3.2 | 203 | +1.6 | 2.8 | 138 | +1.7 | 7 | −1.6 | 20 |
| 6 | −2.0 | 1.8 | 29 | +1.9 | 2.6 | 54 | | | | | | | +6 | 1 | | |
| 7 | −2.1 | 1.9 | 27 | +0.9 | 2.6 | 43 | | | | | | | +1.1 | 11 | | |
| 8 | −1.2 | 2.1 | 22 | +1.1 | 1.5 | 41 | | | | | | | −2.4 | 5 | | |
| 9 | −2.6 | 3.1 | 14 | +0.1 | 1.7 | 38 | | | | | | | −4.0 | 4 | | |
| K0 | −2.9 | 2.5 | 28 | −0.4 | 0.8 | 73 | +0.7 | 2.9 | 112 | +0.4 | 2.4 | 388 | −0.4 | 7 | −3.4 | 38 |
| 1 | −3.0 | 2.4 | 30 | −1.4 | 0.7[s] | 59 | | | | | | | −1.8 | 4 | | |
| 2 | −3.5[s] | 2.3 | 20 | −2.1 | 0.5 | 67 | +3.5 | 1.3 | 35 | +1.6 | 1.4 | 80 | −2.0 | 2 | −2.9 | 10 |
| 3 | −3.9 | 2.6 | 7 | −2.7 | 1.0 | 51 | | | | | | | −2.5 | 4 | | |
| 4 | −4.7 | 1.7 | 14 | −3.0 | 1.4 | 54 | | | | | | | −1.6 | 5 | | |
| 5 | −4.6 | 1.3 | 38 | −2.5 | 2.0[s] | 78 | +1.9 | ±1.4 | 40 | +0.6 | 1.1 | 132 | −2.0 | 4 | −2.0 | 6 |
| 6 | −4.0 | 2.6 | 36 | −1.8† | 1.5 | 77 | +2.3‡ | ..... | 5 | | | | | | | |
| 7 | −3.2* | 1.7 | 22 | −0.8 | 1.6 | 50 | +2.9§ | ..... | 1 | | | | | | | |
| 8 | −3.2 | 1.3 | 8 | −1.0 | 1.1 | 69 | | | | +0.7‖ | 1.0 | 148 | | | | |
| 9 | −4.3 | 1.5 | 7 | −1.2 | 0.8 | 53 | | | | | | | | | | |
| 10 | −5.5 | ±1.6 | 4 | −1.3 | 1.0 | 39 | | | | +0.7¶ | ±0.9 | 49 | | | | |
| 11 | −6.0 | ..... | 1 | −2.0 | ±1.0 | 17 | | | | | | | | | | |
| 12 | | | | −2.3 | ..... | 8 | | | | | | | | | | |
| 13 | | | | −3.3 | ..... | 1 | | | | | | | | | | |
| All | | | 1316 | | | 1010 | | | 983 | | | 973 | | 180 | | 186 |

* MW dM0 = K7.
† MW gM0 = K6.
‡ HD dMa = K6.1:.
§ HD dMb = K7.5:.
‖ HD gMa = K7.7.
¶ HD gMb = K9.7.

To simplify the tabulation, the MW M-type designations have been replaced by an extension of the notation for the K's. The sequence suggested in the MW catalogue[6] and adopted here is

$$gM0 = gK6\ , \qquad dM0 = dK7\ ,\ \text{etc.}$$

Among the giants are numerous HD Ma's and Mb's, and a few of these HD designations also appear among the dwarfs. To utilize these stars—and they must be included

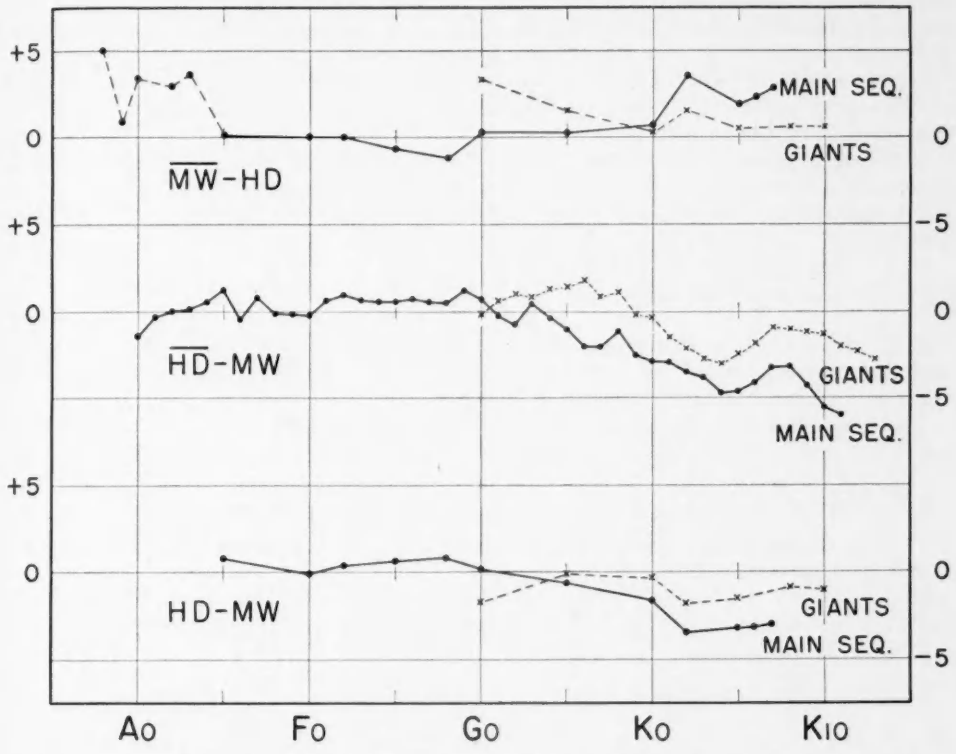


FIG. 3.—Above, regression differences (all magnitudes together) for the HD and the MW classification systems; at the bottom, the "functional" relationship, HD − MW plotted against MW types. The data used (cf. Table 2) are from *Mt. W. Contr.*, No. 511, which includes no MW B-type stars and but few of A0–2. This incompleteness in the data accounts for the large positive differences on the left in the top curve.

—numerical equivalents on the HD system must be found for these symbols. To this end the regression-curve $\overline{MW}$ (abscissae) *vs* HD (ordinates) is plotted as far as HD K5 and then slightly extrapolated. From a direct averaging of MW types for Ma and Mb stars, Ma = $\overline{MW}$ K8.4, Mb = $\overline{MW}$ K10.4. These quantities are the abscissae of points on the extrapolated regression-curve whose ordinates are the required numerical equivalents of Ma and Mb. We thus find Ma = HD K7.7, Mb = HD K9.7. All these equivalents are collected in Table 1. For dwarfs the results are uncertain because of the few stars available; moreover, the interval Mb–Ma, assumed to be the same as for the giants, is doubtful. The equality of $\overline{MW}$ for gMa and dMa is accidental. For neither giants nor dwarfs does the extrapolation of the regression-curve seem to be seriously uncertain.

The range in the MW classifications for the Ma and Mb stars is small. With one exception, all the giant Ma's fall within the MW interval M0–5, the Mb's within M3–7 (altogether, MW K6–13). Numerous HD K0–5 stars also fall within this MW interval, and the regression $\overline{\text{HD}}$ − MW, beginning with MW K6, includes stars having all these designations.

The regression and functional differences shown in Figure 3 suggest that, for types A5–G0 and probably also for A0–A5, the HD and MW systems are nearly the same, the systematic difference rarely exceeding 0.5 of a classification unit. We shall see presently, however, that a complex relationship is concealed beneath the superficial agreement. From G0 on, the statistical influence is large, and for the K's the functional differences themselves are significant and presumably represent the combined influence of differences in classification criteria and in observing conditions—slit-spectrograms as against objective-prism spectra of relatively low dispersion.

The foregoing results ignore any possible dependence on magnitude; and at first sight there seems to be no appreciable influence of this kind. For example, the differences for the A stars, grouped according to $m$, give the following means (followed by the numbers of stars):

$$\begin{array}{lccccccc} m = & < 5.0 & 5.5 & 6.5 & 7.5 & 8.5 & > 9.0 , \\ \overline{\text{HD}} - \text{MW} = & +0.4\ 59 & +0.4\ 95 & +0.4\ 99 & 0.0\ 61 & +0.2\ 51 & +0.4\ 14 . \end{array} \quad (6)$$

For the other classes, with giants and dwarfs together, the results are almost equally satisfactory; and yet, for the A's at least, there is the suspicious circumstance that the arithmetical mean spectral difference is $\pm 3.3$ classification units, the largest of all.

In an attempt to locate the origin of this large difference the A stars were subdivided according to their n and s characteristics and discussed separately. The results are shown in Table 3 and in Figure 4. To the left in the table are the regression differences $\overline{\text{HD}}$ − MW = SD for the subtypes A0–9; on the right, the systematic differences for a grouping according to magnitude. The diagram (which gives the regression lines $\overline{\text{HD}}$ *vs* MW) shows at a glance that important systematic effects are involved. For the stars as a whole, however, these effects neutralize one another almost completely. The apparent homogeneity of the results for A stars, Figure 3 and lines (6), is therefore deceptive.

The $\overline{\text{HD}}$ types for n stars are uniformly later than for s stars.[11] For example, A5n corresponds to $\overline{\text{HD}}$ A7.6, A5s to $\overline{\text{HD}}$ A4.2—a difference of 3.4 units. The irregularity at MW A5–6, which first appears in Figure 2 and can be traced in different magnitude groups, evidently is real. Treated separately, the A0–4 (practically, A2–4, since there are but few A0, 1 stars) and the A5–9 stars give essentially the same magnitude effect. Only for n stars with $m < 5.0$ is there a significant difference between the two groups. The divergences, which are largest for bright stars and zero at about 8.6, are therefore well established for both An and As types.

In calculating the regression differences in Table 3 the magnitude effect was disregarded, and vice versa. A second approximation for the n stars, in which each systematic effect was allowed for in deriving the other, revealed only one change worth noting: the revised $\overline{\text{HD}}$ for A7n falls at the point in the diagram marked by a cross. Both magnitude and regression differences were fully taken into account, however, in computing the values of AE in Table 3 and of SD in the last line of this table. The average AE has been considerably reduced (from $\pm 3.3$ to $\pm 2.8$) by the removal of the systematic effects, but is still large. An average, however, has little meaning because of the well-marked progression in AE. For both n and s stars the precision for the early A's is high, from A5 on surprisingly low. With all known systematic disturbances removed, AE for these late A's is $\pm 3.3$.

[11] Butler and Thackeray (*loc. cit.*) have already noted this difference.

TABLE 3

REGRESSION DIFFERENCES $\overline{HD}$ − MW AND MAGNITUDE EFFECT FOR An AND As STARS
(Unit, 0.1 Sp. Class)

| MW Sp | n Stars | | | s Stars | | | HD n−s | HD Vis. | n Stars | | | s Stars | | | HD n−s |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SD | AE | No. | SD | AE | No. | | | SD | AE | No. | SD | AE | No. | |
| A0 | −1.5 | ±1.4 | 2 | ..... | ..... | ..... | ..... | <5.0 | +2.3 | ±2.0 | 32 | −1.3 | ±2.0 | 30 | +3.6 |
| A1 | −0.1 | 1.2 | 14 | −1.0 | ±0.4 | 3 | +0.9 | 5.5 | +1.8 | 2.4 | 51 | −1.6 | 2.3 | 40 | +3.4 |
| A2 | +0.7 | 2.1 | 24 | 1.2 | 0.8 | 16 | 1.9 | 6.5 | +1.4 | 2.8 | 72 | −2.1 | 3.1 | 28 | +3.5 |
| A3 | +1.0 | 3.1 | 25 | 1.4 | 1.3 | 14 | 2.4 | 7.5 | +0.6 | 2.7 | 36 | −1.3 | 3.3 | 24 | +1.9 |
| A4 | +1.7 | 3.2 | 27 | 0.9 | 1.7 | 15 | 2.6 | 8.5 | 0.0 | 3.4 | 37 | −0.5 | 5.4 | 13 | +0.5 |
| A5 | +2.6 | 3.3 | 34 | 0.8 | 3.2 | 11 | 3.4 | ≥9.0 | −0.3 | ±4.9 | 7 | +1.0 | ±3.8 | 7 | −1.3 |
| A6 | +0.3 | 3.1 | 42 | 2.9 | 2.9 | 14 | 3.2 | | | | | | | | |
| A7 | +2.8 | 2.3 | 23 | 1.8 | 4.2 | 22 | 4.6 | | | | | | | | |
| A8 | +1.0 | 3.4 | 21 | 1.3 | 4.4 | 24 | 2.3 | | | | | | | | |
| A9 | +0.5 | ±2.4 | 23 | −0.7 | ±3.7 | 23 | +1.2 | | | | | | | | |
| All. | +0.02 | ±2.69 | 235 | −0.23 | ±2.86 | 142 | +2.57 | All. | +0.02 | ±2.69 | 235 | −0.23 | ±2.86 | 142 | +2.57 |

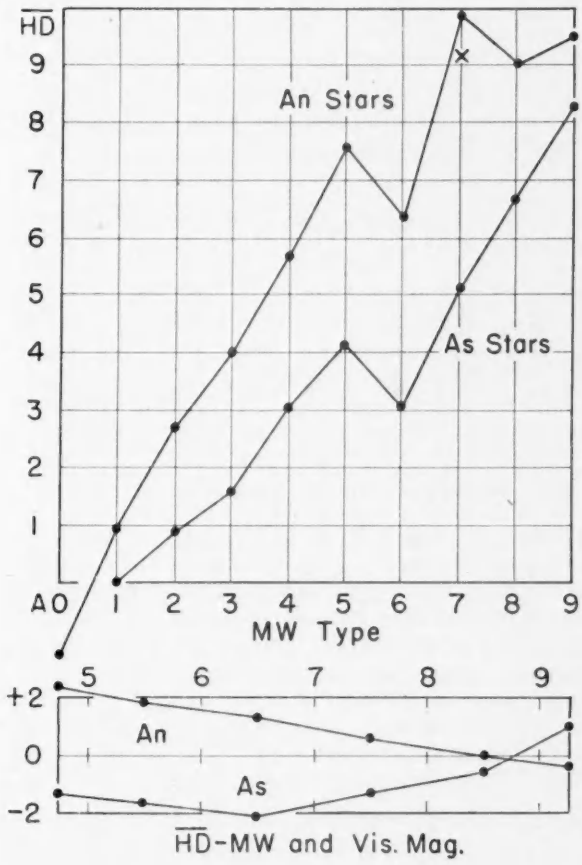


FIG. 4.—Above, regression lines $\overline{HD}$ *vs* MW for MW An and As stars; below, magnitude effect in the spectral differences HD − MW for An and As stars. The systematic differences shown here neutralize one another when all the data are plotted together, as in Figure 3, middle curve. For numbers of stars used see Table 3.

The systematic difference in the HD types corresponding to n and s stars of the same MW types (Table 3, last col.) indicates that n stars should be appreciably redder than s stars. The matter can be tested for 46 n and 24 s stars which occur in the *Göttingen Aktinometrie*. Corrected for right-ascension error by B. Sticker's curve,[12] the Göttingen-Potsdam color indices give a mean difference n − s = +0.08 ± 0.03 (ME) mag. The rejection of two very blue stars with peculiar spectra leaves +0.06. The value to be expected for the same distribution of types and magnitudes on the basis of Table 3 is +0.07 mag.

Evidence on the magnitude effect for F–K stars is given in Table 4. Types F and gG–K show no progression in the values of SD, only zero-point differences corresponding to the mean ordinate of the regression-difference curves of Figure 3 for the spectral

TABLE 4

MAGNITUDE EFFECT IN $\overline{HD}$ − MW DIFFERENCES

| HD Vis. | SD | AE | No. | SD | AE | No. | SD | AE | No. | SD | AE | No. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | F0–9 | | | F0–9* | | | dG5–9 | | | dK0–6 | | |
| <5.0 | +0.6 | ±1.9 | 30 | −0.8 | ±2.1 | 40 | +0.2 | ±1.6 | 5 | −1.3 | ±1.5 | 6 |
| 5.5 | 0.2 | 2.1 | 99 | +0.2 | 1.9 | 102 | −1.3 | 1.2 | 15 | 2.5 | 2.2 | 13 |
| 6.5 | 0.0 | 1.9 | 101 | +0.2 | 2.0 | 110 | −2.4 | 2.2 | 33 | 3.8 | 2.3 | 25 |
| 7.5 | 0.4 | 2.1 | 66 | +0.1 | 2.1 | 59 | −1.6 | 2.3 | 37 | 3.5 | 1.8 | 46 |
| 8.5 | +1.1 | ±2.4 | 47 | +0.2 | ±2.5 | 49 | −1.6 | 2.2 | 37 | 4.5 | 2.2 | 65 |
| ⩾9.0 | ..... | ..... | ... | ..... | ..... | ... | −1.0 | ±1.1 | 4 | −3.6 | ±2.6 | 18 |
| All | +0.33 | ±2.05 | 343 | +0.08 | ±2.09 | 360 | −0.05 | ±2.06 | 131 | −0.09 | ±2.13 | 173 |
| | gG4–6 | | | gG7–9 | | | gK0–2 | | | gK3–5 | | |
| <5.0 | +1.5 | ±2.7 | 16 | +1.1 | ±2.0 | 14 | −0.9 | ±0.0 | 31 | −2.3 | ±1.4 | 35 |
| 5.5 | 1.7 | 2.0 | 46 | 0.5 | 1.8 | 43 | 1.7 | 0.8 | 73 | 3.2 | 1.6 | 80 |
| 6.5 | 1.2 | 2.5 | 33 | 0.7 | 2.2 | 45 | 1.4 | 0.6 | 60 | 2.1 | 1.6 | 49 |
| 7.5 | 2.2 | 2.4 | 14 | 0.2 | 1.9 | 10 | 0.6 | 1.4 | 27 | 1.8 | 2.0 | 12 |
| 8.5 | +2.7 | ±1.2 | 6 | +2.1 | ±1.5 | 10 | −0.5 | ±1.6 | 8 | −3.6 | ±1.2 | 7 |
| All | +0.10 | ±2.23 | 115 | −0.03 | ±1.95 | 122 | −0.30 | ±0.70 | 199 | −0.01 | ±1.56 | 183 |

* For the $\overline{MW}$ − HD differences; the remainder of the table is based on values of $\overline{HD}$ − MW.

interval concerned. The dK's, however, reveal a conspicuous divergence. Similar tabulations for several other groups of subtypes between dG5 and dK6 lead to the series of smoothed differences given in Table 4*a*, from which it appears that the effect becomes appreciable at about dG7. The divergence develops among the bright stars, and from the sixth magnitude downward SD remains practically constant for each subtype. Only 40 stars fall in the critical regions, and the divergence is masked by the numerous giants (about 340) when giants and dwarfs are discussed together.

The accidental errors (AE), as usual, have been freed from systematic effect. Except for gK, AE is sensibly constant and equal to ±2.1 classification units. To the AE's in Table 4 for groups of subtypes the following may be added:

dM0–3 ±1.58 41 stars, gM0–5 ±1.21 305 stars,

which are comparable with and a little better than the mean for gK3–5.

[12] *Veröff. der Univ. Sternwarte zu Bonn*, No. 23, p. 8, 1930. There is good reason for believing that this double-period variation in the color indices of the *Aktinometrie* is mainly the result of space absorption. The stars are reddest at $6^h$ and $19^h$ R.A., where the Milky Way cuts through the 20° zone of the catalogue.

The values for A5–9 ($\pm 3.3$) and for gK0–2 ($\pm 0.7$) are notable deviations from the average. The values of AE for individual subtypes, except the A's which are in Table 3, are listed in Table 2. This table also includes AE for the individual HD subtypes. Owing to differences in the HD and MW classification errors, there is no close relationship between the two series. For the F's the AE's are equal (Table 4); for gK0, on the other hand (Table 2),

$$\overline{\text{HD}} - \text{MW}, \quad \pm 0.8\,; \qquad \overline{\text{MW}} - \text{HD}, \quad \pm 2.4\,.$$

The smaller value shows that practically all MW gK0 stars are also HD K0 (the systematic difference for gK0 is negligible); the larger, that many HD K0 stars have MW types other than gK0. The full range in the HD error thus shows only when HD is the basis of grouping.

Judged by the numbers of stars involved, the larger fluctuations in AE must be real. Chance groupings of exceptional accidental errors will not account for them. In seeking for explanations the possibility of obscure statistical influences must be borne in mind.

TABLE 4*a*

MAGNITUDE EFFECT FOR DWARF STARS*

| HD vis | G5 | G6 | G7 | G8 | G9 | K0 | K1 | K2 | K3 | K4 | K5 | K6 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| <5.0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| 5.5 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 2 | 2 | 3 | $2^5$ | 2 |
| 6.5 | 1 | 2 | 2 | 3 | 3 | 3 | 3 | 4 | 4 | 5 | 5 | 5 |
| 7.5 | 1 | $1^5$ | 2 | 2 | 2 | 2 | $2^5$ | 3 | $3^5$ | 4 | 4 | 4 |
| 8.5 | 1 | $1^5$ | 2 | 2 | 3 | 2 | 4 | 4 | $4^5$ | 5 | 5 | 5 |
| ≥9.0 | 1 | 1 | 2 | 2 | 3 | 3 | 3 | 4 | 4 | 4 | 4 | 4 |

* Smoothed values of $\overline{\text{HD}}$ − MW, unit 0.1 spectral class; algebraic sign negative throughout.

The unequal intervals of the HD classification scale, for example, undoubtedly play a part in the matter. In the region G0–K0, with G5 the only intermediate subtype, the errors should be larger, other things being equal, than among the F's, where, besides F5, the designations F2 and F8 are used. Measured by other physical characteristics, such as color index or reciprocal temperature, these interval differences are certainly real and nearly proportional to the values indicated by the decimal subdivision of the spectral classes. The MW system, on the other hand, proceeding everywhere by unit steps, should show a nearly constant error (other things again being equal). Since $(\text{AE})^2 = \epsilon^2_{\text{HD}} + \epsilon^2_{\text{MW}}$ (average errors), the HD inequalities should be reflected in AE.

For the $\overline{\text{MW}} - \text{HD}$ series we should therefore expect a correlation of AE for any subtype with the length of interval separating the adjacent subtypes, for example, 10 spectral units for G5. Actually, we find

$$\overline{\text{MW}} - \text{HD} \begin{cases} \text{Interval} = 5 & 6 & 7 & 10 & \text{sp. units} \\ \text{Mean AE} = \pm 1.7 & \pm 1.4 & \pm 2.3^5 & \pm 3.0 & \text{sp. units} \\ \text{No.} = 4 & 3 & 6 & 2 & \end{cases} \qquad (7)$$

For the alternative grouping we may use as a criterion the minimum value of HD − MW for each of the successive MW subtypes. Thus for MW G0, G1, and G2 the minimum values, since HD G1 and G2 do not occur, are 0, 1, and 2. In application the matter is a little more complicated than before, because the systematic regression differences must be taken into account, which brings fractional values into the calculation. Moreover, the A stars cannot be used because of the magnitude effect, at least not without

much extra work. For the dwarfs, however, this disturbance can be disregarded; the number of stars affected is too small to be of any consequence. The results are:

$$\overline{HD} - MW \begin{cases} \text{Min. Diff.} = & 0.1 & 0.5 & 0.9 & 1.4 & 2.0 & \text{sp. units} \\ \text{Mean AE} = & \pm 1.7 & \pm 1.7 & \pm 1.9 & \pm 2.5 & \pm 2.6 & \text{sp. units} \\ \text{No.} & 9 & 10 & 10 & 8 & 6 & \end{cases} \quad (8)$$

The statistical effect sought for is in both cases superimposed on any intrinsic differences that may be present; and yet the progression in AE is clear enough in both tabulations (7) and (8). As for the neglected A stars, the scale intervals are such as to account for part, but probably not all, of the change in AE between early and late subtypes.

### III. MOUNT WILSON–HUMASON ($MW_H$) AND HARVARD (HD)

Since the stars in the Selected Areas observed by Humason are generally much fainter than those in the HD, the number classified in common is small—less than 200 in all. Detailed analysis is therefore not possible. The regression differences are in the last two divisions of Table 2. The mean systematic differences and the average errors, for all types together, are grouped according to magnitude in Table 5. The general agreement

TABLE 5

MAGNITUDE EFFECT AND AVERAGE ERROR

| Pg $m$ | $\overline{MW_H}$ − HD | | No. | Pg $m$ | $\overline{MW_H}$ − HD | | No. |
|---|---|---|---|---|---|---|---|
| | SD | AE | | | SD | AE | |
| 6.7 | +1.2 | ±2.6 | 9 | 9.8 | +0.3 | ±3.4 | 18 |
| 7.5 | +1.1 | 1.9 | 27 | 10.2 | −0.8 | ±3.4 | 14 |
| 8.2 | +0.6 | 2.5 | 31 | | | | |
| 8.8 | +0.2 | 2.9 | 40 | All | +0.2 | ±2.9 | 186 |
| 9.2 | −0.4 | ±3.5 | 47 | | | | |

in zero point is close, and there is no certain dependence on magnitude. The larger AE for faint stars probably reflects the increased difficulty of the HD classification for these stars.

The functional relation, which has been used in the discussion of the Bergedorf classification, appears in the second and third columns of Table 12. The largest differences in the smoothed relation are of the order of 1 unit. For K stars the agreement is better than that between MW and HD.

### IV. UPSALA-PETERSSON (U) AND HARVARD (HD)

The stars used for the regression differences (Table 6) are those classed by Petersson as A5 or later for which MW color indices are available. The large values of $\overline{U}$ − HD for A2 and A3 have no general significance because they originate in the peculiar selection of the data. About 40 B and early A stars for which the U designations follow the notation of Lindblad could not be included, owing to the lack of numerical equivalents. These latter stars, however (supplemented by some others), permitted an approximate calibration of the U symbols and aided in the test for magnitude effect (Table 7).

Petersson has been generally successful in discriminating between giants and dwarfs, but for use here a few of his designations have been changed because of what seemed to be more convincing evidence from the color indices.

TABLE 6

REGRESSION DIFFERENCES

| Sp | $\overline{U} - HD$ | | | | $\overline{HD} - U$ | | | | $\overline{Bg} - MW_H$ | | $\overline{MW_B} - Bg$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Main Seq. | | Giants | | Main Seq. | | Giants | | | | | |
| | SD | No. | SD | No. | SD | No. | SD | No. | SD | No. | SD | No. |
| B4 | | | | | | | | | +1.3 | 13 | +1.3 | 10 |
| 7 | | | | | | | | | | | +3.3 | 9 |
| 8 | | | | | | | | | +2.4 | 12 | +0.9 | 13 |
| 9 | | | | | | | | | +1.1 | 7 | +1.2 | 23 |
| A0 | | | | | | | | | +0.9 | 64 | +1.5 | 44 |
| 1 | | | | | | | | | +1.2 | 24 | +0.7 | 15 |
| 2 | +5.0 | 5 | | | | | | | +1.0 | 28 | −0.1 | 23 |
| 3 | +4.0 | 6 | | | | | | | −0.3 | 17 | −0.6 | 16 |
| 4 | | | | | | | | | −0.6 | 22 | +1.5 | 4 |
| 5 | +2.8 | 6 | | | −0.2 | 13 | | | +1.2 | 21 | −1.7 | 33 |
| 6 | | | | | | | | | +2.5 | 10 | −0.8 | 6 |
| 7 | | | | | | | | | +2.1 | 13 | −2.2 | 4 |
| 8 | | | | | | | | | +2.7 | 9 | −0.8 | 44 |
| 9 | | | | | | | | | −0.6 | 14 | +2.0 | 2 |
| F0 | +0.5 | 14 | | | −1.5 | 12 | | | +5.5 | 13 | +2.9 | 15 |
| 1 | | | | | | | | | +2.3 | 14 | +1.0 | 2 |
| 2 | +1.3 | 9 | | | −0.4 | 18 | | | +0.7 | 21 | −0.5 | 21 |
| 3 | | | | | | | | | +5.3 | 15 | −2.0 | 17 |
| 4 | | | | | | | | | +2.9 | 17 | +1.2 | 5 |
| 5 | −1.1 | 17 | | | +1.3 | 19 | | | +2.8 | 27 | +1.2 | 34 |
| 6 | | | | | | | | | +2.5 | 36 | +0.1 | 14 |
| 7 | | | | | | | | | +1.9 | 50 | −0.4 | 29 |
| 8 | −1.1 | 11 | | | +0.3 | 14 | | | +1.8 | 53 | +1.1 | 70 |
| 9 | | | | | | | | | +1.8 | 43 | −0.2 | 9 |
| G0 | −2.2 | 13 | | | +1.7 | 12 | | | +0.6 | 56 | −0.2 | 123 |
| 1 | | | | | | | | | +0.2 | 36 | −1.2 | 17 |
| 2 | | | | | | | | | −1.2 | 53 | −1.5 | 80 |
| 3 | | | | | | | | | −1.0 | 44 | −0.8 | 79 |
| 4 | | | | | | | | | −0.9 | 44 | −0.1 | 12 |
| 5 | −1.0 | 19 | +1.4 | 14 | +1.4 | 11 | +1.2 | 12 | −1.7 | 44 | −1.1 | 74 |
| 6 | | | | | | | | | −0.7 | 23 | +0.1 | 16 |
| 7 | | | | | | | | | −1.2 | 34 | −1.2 | 34 |
| 8 | | | | | +0.2 | 11 | +0.5 | 13 | −1.7 | 32 | +0.2 | 46 |
| 9 | | | | | | | | | −1.7 | 22 | +3.5 | 2 |
| K0 | −2.3 | 17 | −0.2 | 27 | −0.5 | 6 | +0.8 | 12 | −1.8 | 29 | −0.3 | 32 |
| 1 | | | | | | | | | −3.1 | 18 | +0.7 | 3 |
| 2 | −2 | 1 | +0.2 | 10 | −1.0 | 2 | −0.6 | 11 | −1.0 | 16 | −2.6 | 25 |
| 3 | | | | | | | | | −3.4 | 19 | −0.4 | 21 |
| 4 | | | | | | | | | −3.2 | 8 | −3.5 | 4 |
| 5 | | | −2.2 | 5 | | | −3.2 | 8 | −2.4 | 20 | −1.7 | 12 |
| 6* | | | | | | | | | +0.1 | 8 | −1 | 1 |
| 7 | | | | | | | | | −2 | 1 | +0.3 | 3 |
| 8 | | | | | | | | | −3 | 1 | −2.0 | 10 |
| 9† | | | | | | | | | −1.0 | 5 | −1.2 | 5 |
| 10 | | | | | | | | | −2.0 | 2 | | |
| 11 | | | | | | | | | −5.0 | 3 | | |
| All | | 118 | | 56 | | 118 | | 56 | | 1061 | | 1061 |

* MW M0–5 = K6–11.

† Bg Ma = Bg K9.

To reduce the influence of accidental error, the values of HD − U in Table 7 are the means for groupings according to both the HD and the U classifications. There seems to be no appreciable magnitude effect. Since HD classifications for many of the U early A's are lacking, the calibration of the U symbols was made through the color indices and signifies only an equality of color between the U and the adopted HD type. Final results for this calibration, differing but little from those used here, are given in Table 8 of the following *Contribution*.

TABLE 7

MEAN HD − U FOR GROUPINGS ACCORDING TO BOTH HD AND U

| Pv *m* | A* | F | G | K | All |
|---|---|---|---|---|---|
| 4.5 | ..... | ..... | −0.8 1 | +0.1 3 | −0.1 4 |
| 5.4 | +0.4 5 | ..... | ..... | ..... | +0.4 5 |
| 6.4 | ..... | −0.8 9 | ..... | −1.4 5 | −1.0 14 |
| 7.3 | +0.5 12 | −0.9 11 | −0.3 10 | +0.2 11 | −0.1 44 |
| 7.9 | −0.3 12 | −0.1 15 | −0.8 10 | 0.0 10 | −0.3 47 |
| 8.2 | −0.7 12 | ..... | −0.1 16 | +0.9 12 | 0.0 40 |
| 8.8 | +0.3 12 | +0.8 23 | +1.1 14 | −0.5 10 | +0.5 59 |
| All | +0.6† 53 | +0.2 58 | +0.8 51 | +0.2 51 | .....213 |
| AE | ±1.7.... | ±2.4.... | ±2.4.... | ±1.7.... | |

* Includes 5 HD B stars.

† The differences in the body of the table have been corrected by this value of SD for all the A stars. Similarly for other types.

## V. BERGEDORF (Bg) AND MOUNT WILSON–HUMASON ($MW_H$)

Classifications of 1206 stars in Selected Areas 1–43 are available, but for the 7 Areas shown in the accompanying tabulation the mean zero-point differences are so much

| Area | $MW_H$ − Bg | No. Stars | Area | $MW_H$ − Bg | No. Stars |
|---|---|---|---|---|---|
| 11 | −3.0 | 24 | 17 | +3.0 | 36 |
| 12 | −3.2 | 15 | 32 | +4.4 | 16 |
| 15 | +2.7 | 15 | 33 | +4.0 | 16 |
| 16 | −2.8 | 27 | | | |

larger than usual that these Areas have been excluded from the discussion. The average of these differences is nearly five times that for the remaining 36 Areas and can only be regarded as abnormal.

The regression differences are in the last two divisions of Table 6, the magnitude effect and the AE's in Tables 8 and 9. The irregularities for A9–F3 stars, suggesting a large accidental error, confirmed by Table 9, have already been mentioned. A dependence on magnitude shows in the differences for early types but disappears at about G0. The numerical evaluation of Bg Ma (= Bg K9) depends on only five stars.

## VI. BERGEDORF (Bg) AND HARVARD (HD)

Fragmentary comparisons of Bg with U and with HD, which cover only the small field of Selected Area 1, are given in Tables 10 and 11. Some irregularities depending on magnitude are suggested but scarcely established by the meager data.

In the introduction to his catalogue of spectra Schwassmann[9] has given values of the regression $\overline{Bg}$ *vs* HD which depend on extensive data. Later, E. Holmberg,[13] with the aid of the correlation coefficient and the dispersions, derived the second regression, which is essential for the reduction of Bg to the HD system. Incidentally, the low-weight differences in the right half of Table 10 are not in disagreement with these more reliable results. Important as the relations of Schwassmann and Holmberg are, they include data only to the limit of the HD, whereas the Bg classifications extend to stars 3 or 4 mag. fainter.

TABLE 8

$\overline{Bg} - MW_H$* DEPENDENCE ON MAGNITUDE

| Bg Pg | B8—A8 | F4—F9 | G0—G4 | G5—G9 | K0—K5 | M0—M5 | All | AE |
|---|---|---|---|---|---|---|---|---|
| < 8.0... | −1.6 8 | ..... | ..... | −5.8 3 | ..... | ..... | −2.9 11 | ±2.7 |
| 8.5... | −1.2 12 | −4.1 2 | +4.2 6 | ..... | −3.6 2 | ..... | −0.2 22 | 2.0 |
| 9.5... | −1.0 25 | −0.1 5 | +1.8 9 | −1.0 4 | +1.2 8 | +1.4 2 | 0.0 53 | 2.9 |
| 10.5... | −0.7 38 | −2.5 15 | −1.0 18 | +0.7 20 | −0.6 14 | −0.1 4 | −0.7 109 | 2.4 |
| 11.2... | −0.6 35 | −0.9 22 | −0.6 25 | +0.7 12 | −0.2 18 | −1.3 3 | −0.5 115 | 3.0 |
| 11.8... | +0.6 41 | −0.3 36 | +0.1 24 | +0.6 21 | −0.4 21 | −0.6 2 | +0.1 145 | |
| 12.2... | +0.5 34 | −0.4 42 | −0.2 43 | +0.6 28 | −0.3 13 | −1.3 3 | +0.1 163 | 2.9 |
| 12.8... | +1.6 20 | +0.9 43 | +0.2 38 | −0.5 25 | +0.9 17 | −0.3 3 | +0.5 146 | |
| 13.2... | +2.7 14 | +0.9 52 | −0.8 52 | −1.0 29 | +0.2 12 | +2.4 3 | +0.1 162 | ±3.1 |
| 13.8... | ..... | +1.3 8 | +1.7 15 | +1.6 11 | +0.6 5 | ..... | +1.4 39 | |
| All... | ..... | ..... | ..... | ..... | ..... | ..... | 0.0 965 | ±2.9 |

* Grouped according to Humason's spectra and corrected for the mean SD given in the last division but one of Table 6.

TABLE 9

SUMMARY, TYPE, AND AE

| Sp | $\overline{Bg} - MW_H$ | $\overline{MW}_H - Bg$ | Sp | $\overline{Bg} - MW_H$ | $\overline{MW}_H - Bg$ |
|---|---|---|---|---|---|
| B..... | ±2.3 32 | ±1.5 55 | K, M..... | ±2.8 125 | ±3.0 116 |
| A..... | 2.8 222 | 2.7 191 | | | |
| F..... | 3.3* 289 | 3.5 216 | All.... | ±2.9 1056 | ±3.1 1061 |
| G..... | ±2.8 388 | 3.2 483 | | | |

* AE for 77 A9–F3 stars = ±4.5.

Some additional evidence on the second regression-curve is given in Table 12. The first and second columns define the regression $\overline{MW}_H$ *vs* Bg (from the first column and last division of Table 6), and the second and third the functional relation of $MW_H$ to HD (based on the last two divisions of Table 2). Since $\overline{MW}_H$ and $\overline{HD}$ are corresponding values, presumably free from statistical error, the third and first columns of Table 12 together represent an independent determination of the regression $\overline{HD}$ *vs* Bg. The disadvantage here is that the functional relationship of $MW_H$ and HD depends on stars to the limit of HD only, whereas the values of $\overline{MW}_H$ in the second column of Table 12 include much fainter stars. Nevertheless, the regression differences $\overline{HD} - Bg$ found from the first and third columns and shown in the fourth column have the same general form as those from Holmberg's discussion (fifth column). The A stars alone are to be

[13] *Lund Medd.*, Ser. 1, No. 146, 1937.

excepted, the discordance for which may be traced to the magnitude effect in $\overline{Bg} - MW_H$ for the spectral interval B8–A8 shown in Table 8. In fact, the agreement between the fourth and fifth columns of Table 12 is rather too good, since corresponding values depend upon the frequency distribution of spectral types to different limiting magnitudes—about 13 and 9, respectively.

The differences in the last two columns of Table 12 do not properly belong under the heading $\overline{HD} - Bg$, since they represent an indirect comparison made through the color

TABLE 10

REGRESSION DIFFERENCES

| Sp | $\overline{Bg} - U$ | | $\overline{U} - Bg$ | | AE | $\overline{Bg} - HD$ | | $\overline{HD} - Bg$ | | AE |
|---|---|---|---|---|---|---|---|---|---|---|
| B | ..... | | ..... | | ..... | +1 | 1 | −1 | 1 | ±1.0 |
| A | 0 | 1 | +1.5 | 2 | ±1.0 | +0.2 | 4 | +2.2 | 6 | 2.0 |
| F | +2.2 | 12 | −1.0 | 7 | 2.7 | −2.0 | 6 | +0.6 | 7 | 1.8 |
| G | +0.2 | 9 | −1.4 | 14 | 2.2 | +0.5 | 6 | +0.9 | 8 | 2.9 |
| K | −1.4 | 5 | +0.8 | 4 | ±2.0 | −1.1 | 8 | −2.3 | 3 | ±2.7 |
| All | ..... | 27 | ..... | 27 | ±2.3 | ..... | 25 | ..... | 25 | ±2.3 |

TABLE 11

DEPENDENCE ON MAGNITUDE

| Pv $m$ | $\overline{U} - Bg$ | | | | $\overline{HD} - Bg$ | |
|---|---|---|---|---|---|---|
| | All Types | | F Stars | | | |
| 6.5 | +4 | 1 | ..... | | −0.7 | 3 |
| 7.5 | −3 | 1 | ..... | | −1.5 | 4 |
| 8.5 | +0.2 | 6 | +0.5 | 2 | +1.1 | 12 |
| 9.5 | −0.5 | 6 | −1.0 | 3 | +1.8* | 6 |
| 10.3 | −0.9 | 7 | −3.3 | 3 | | |
| 10.8 | −2.3 | 6 | −3.5 | 4 | | |
| All | −0.8 | 27 | −2.2 | 12 | +0.6 | 25 |

* Value for Pv $m$ = 9.0.

indices. In preparing *Contribution* No. 684, the regressions of $\overline{C}$ (color index corrected for space absorption, that is, reduced to zero distance) on HD and on Bg were found from the stars for which MW colors are available. For the first regression the magnitude limit is that of the HD, for the latter that of $C$ itself, about 9 and 11 photovisual, respectively. The quantities in the last column of Table 12 are the corrections to Bg which reduce the second regression to the system of the first, that is, to that of $\overline{C}$ on HD. This reduction allows for any influence arising from the difference in limiting magnitudes.

### VII. YERKES–KEENAN AND BABCOCK (Y) AND HARVARD (HD)

The Yerkes classifications are from slit spectrograms of about 70 stars in the polar region, nearly all of HD type A0 (10 B9 stars; 2 B8). The mean differences in Table 13 show no appreciable magnitude effect, only a zero-point difference of +1 spectral unit. The unusually small AE for the differences is also noteworthy.

Another list, including 36 stars,[10] mostly of declinations 40°–50°, give for fifth- and sixth-magnitude stars values of SD similar to those in Table 13. For still brighter stars, however, SD seems to approach zero. It is important to note that both these lists are essentially selections of HD A0 stars. Any attempt to obtain from them values of the regression $\overline{HD} - Y$ will therefore give fallacious results. To reduce Y to the HD system we can use only a constant value—the SD of Table 13 with the sign reversed.

For about half the stars, n and s characteristics have been recorded, but they contribute nothing to the relationships found for such stars from the $\overline{HD} - MW$ comparison. There is no certain systematic difference n − s; but for A0 stars there should be only a magnitude effect at most, and many of the stars fall in the interval in which this effect is small. Moreover, any safe comparison with the results in section ii would require the alternative regression $\overline{HD} - Y$, which is unavailable.

TABLE 12

REGRESSIONS $\overline{MW}_H$ AND $\overline{HD}$ *vs* Bg

| Bg | $\overline{MW}_H$ | $\overline{HD}$* | $\overline{HD} - Bg$ DERIVED FROM | | | |
|---|---|---|---|---|---|---|
| | | | Regression Lines† | Holmberg‡ | Color Indices | |
| B5 | B6.4 | B8.1 | +3.1 | +3 | | |
| 8 | 9.5 | 9.8 | +1.8 | +2 | | |
| A0 | A1.0 | A0.5 | +0.5 | +2 | | |
| 2 | 2.3 | 1.2 | −0.8 | +2 | | |
| 5 | 4.0 | 3.0 | −2.0 | +2 | −1.0 | |
| 8 | 7.2 | 7.8 | −0.2 | ..... | −1.2 | |
| F0 | 9.5 | F1.1 | +1.1 | +1 | +0.5 | Giants |
| 2 | F2.2 | 3.5 | +1.5 | +1 | +0.3 | |
| 5 | 5.3 | 5.5 | +0.5 | +1 | −0.8 | |
| 8 | 8.4 | 8.4 | +0.4 | +1 | −2.7 | |
| G0 | 9.8 | G0.0 | 0.0 | 0 | −3.0 | +0.8 |
| 2 | G1.0 | 1.5 | −0.5 | ..... | −1.5 | +1.0 |
| 5 | 4.0 | 5.4 | +0.4 | 0 | 0.0 | +1.8 |
| 8 | 7.4 | 8.6 | +0.6 | ..... | +1.6 | +1.1 |
| K0 | 9.3 | K0.1 | +0.1 | 0 | +1.3 | +1.0 |
| 2 | K1.0 | 1.4 | −0.6 | −1 | +1.3 | +0.6 |
| 5 | 4.4 | 4.1 | −0.9 | −1 | | |

* $\overline{HD}$ from functional relation with $MW_H$ as argument. Based on Table 2.

†"Regression Lines" based mostly on stars fainter than magnitude 9 Pv. Magnitude effect for B8–A8 stars accounts for most of systematic difference relative to Holmberg.

‡ *Lund Medd.*, Ser. 1, No. 146, 1937. Direct comparison with HD Sp.; mag. limit = 9 Pv.

TABLE 13

$\overline{Y} - HD$

| Pv *m* | SD | AE | No. | Pv *m* | SD | AE | No. |
|---|---|---|---|---|---|---|---|
| 5.8 | +0.8 | ±1.4 | 7 | 8.2 | +0.9 | ±1.1 | 16 |
| 6.7 | 1.0 | 1.2 | 8 | 9.0 | +1.4 | ±1.6 | 19 |
| 7.3 | 0.8 | 1.2 | 9 | | | | |
| 7.7 | +0.8 | ±1.1 | 12 | All | +1.0 | ±1.3 | 71 |

The general freedom of the foregoing results from magnitude errors is in agreement with the conclusion reached by Vyssotsky.[2] Aside from the systematic difference for the An and As stars and for the late-type dwarfs of the $\overline{\text{HD}}$ − MW comparison, the only noteworthy progression with magnitude is that for early-type stars appearing in Table 8; and here it is difficult to distinguish between classification errors and modifications of the regression differences produced by changes in the frequency distribution of spectral types. Nevertheless, well-marked progressive magnitude effects are known to occur,[14] and there is evidence also of the occurrence of systematic errors for stars close to the classification limit. The latter, however, are generally smoothed out and obscured in the means for the groups of faint stars. They are clearly in evidence, nevertheless, in the data illustrated in Figure 2 of the following *Contribution* (No. 684). With the exception of the late-type dwarfs in the MW − HD comparison, the "functional" differences between the various classification systems seldom exceed 1 unit.

[14] For example, between the HD and the MW classifications of A stars near the galactic poles (Stebbins, Huffer, and Whitford, *Mt. W. Contr.*, No. 650, Table 1; *Ap. J.*, **94**, 217, 1941).

# DISCUSSIONS OF COLOR INDEX AND SPECTRAL TYPE*

FREDERICK H. SEARES[1] AND MARY C. JOYNER
Mount Wilson Observatory
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## ABSTRACT

Color indices from the *Mt. W. Polar Catalogue* and numerous observations of spectral types made at Upsala, Harvard, Bergedorf, Yerkes, and Mount Wilson give the following results:

1. *Information on the consistency of the color indices.*—For stars brighter than $m = 9.0$ and types earlier than G0 the colors require a correction depending on the magnitude (Fig. 3).

2. *A determination of the spectrum-color relation* (Table 7, Fig. 4; international system for color, HD for spectra).—Freed from the effects of space absorption, $C$ for A0 is $-0.15$ mag., in agreement with results from stars in unobscured regions.

3. *A determination of the mean color excess* E *as a function of distance* (Table 11, Fig. 5).—To 400 parsecs (distance corrected for absorption) $E$ increases at the rate of about 0.06 mag. per 100 parsecs. From 450 to about 700 parsecs it has an approximately constant value of 0.27 mag., as though the obscuring cloud ended a little beyond 400 parsecs. The corresponding absorptions for photographic and photovisual light ($\lambda^{-1}$ law) are 1.3 and 1.0 mag., respectively.

The foregoing results leave for each star a residual (about 1350 in all) which includes the influence of deviations from the mean absorption $E$, of dispersion in color for stars of the same spectrum, and of observational errors in color and in spectrum. The statistical relationships are such that these influences can be partially separated and estimated.

Local zero-point errors (ME) in $C$ for the *Mt. W. Polar Catalogue* are about $\pm 0.015$ mag. (Table 12, relation [19]).

Deviations from the mean $E$ are appreciable but apparently local; the obscuring cloud extends over the polar cap north of $+80°$ with little evidence of progressive change from side to side (Table 12, Figs. 6, 7).

Except for types later than about K2, the dispersion in color for the same spectrum averages less than $\pm 0.035$ mag. (Table 13, relation [25]). For late K and M giants it seems to be 0.1 mag. or more.

Spectral-classification errors (Tables 14–14*b*) for early A's and for gK stars are generally smaller than for intermediate types. Slit spectrograms naturally show a higher precision than objective-prism plates; the errors for MW (only 53 stars available) average from 0.6 to 0.8 those for the HD in the polar region, which for most types seem to be less than the average for the HD as a whole.

## I. INTRODUCTION

The *Mount Wilson Polar Catalogue*[2] gives color indices for a thousand or more stars for which spectral types are also known. Each of these stars provides an equation of the form

$$C - \delta C - E - C_s = v \,, \qquad (1)$$

in which

$C$ = The observed color index from the *Catalogue;*

$\delta C = R(m, S)$, a term introduced to take account of any systematic error in $C$ depending on the star's magnitude $m$ or its spectral type $S$;

$E = R_1(\rho, S)$, the star's color excess, depending on the space-absorption coefficient, the distance $\rho$, and, theoretically at least, on the temperature (or spectrum) of the star; the absorption coefficient is omitted from the symbol since it does not appear explicitly in the present discussion;

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington,* No. 684.

[1] Research Associate, Carnegie Institution of Washington.

[2] Seares, Ross, and Joyner, *Magnitudes and Colors of Stars North of +80°; Carnegie Institution Publication 532,* 1941.

$C_s$ = $R_2(S, M)$, the color index inferred from the spectral type; for later types, certainly, the influence of the absolute magnitude $M$ must be taken into account;

$R_1$ and $R_2$ are statistical relations whose values for any specified $\rho$, $S$, and $M$ are the averages defined by all the stars available. Hence, on the right of (1),

$v$ = A residual which includes not only the accidental observation errors in $C$ and $S$ but also the deviations of $C$ and $E$ peculiar to the star in question from the corresponding averages for $R_1$ and $R_2$. Since we deal with averages, $R_1$ and $R_2$ may properly be called functions of $\rho$, $S$, etc.

The three relations appearing in equation (1) are important: that for $\delta C$ because it bears on the consistency of the color indices of the *Polar Catalogue;* that for $E$ because of our interest in the obscuring cloud that veils the polar region; and that for $C_s$ because it is the fundamental color-spectrum relation which continually appears in astrophysical discussions. At present the values of $\delta C$ are unknown.[3] For $E$ we have some early Mount Wilson estimates[4] and, among others, the results of Stebbins, Huffer, and Whitford,[5] the latter of excellent precision but derived from a small number of stars. Of $C_s$ there are many determinations, but none referred to the international system of color that is complete or wholly satisfactory.[6]

It is therefore proposed to derive these relations from the color-spectrum data now available. For all stars together the sum of the residuals $v$ will, of course, be zero; moreover, the corresponding sums for selected groups—say, those of a given spectrum or of a given magnitude—will at least be negligibly small. By dealing with groups and disregarding residuals, the solution becomes determinate, although successive approximations must be used if the best values are to be obtained.

$C_s$ for late-type stars, although dependent on $M$, can be found only for the two broad luminosity divisions of dwarfs and giants—actually the normal giants, since these are by far the most numerous of the high-luminosity stars.

Equation (1) makes no provision for the influence of a magnitude error in the spectral types, which would operate precisely as one in $C$ itself. The solution gives, in fact, the combined effect, and the two errors must be separated by special criteria. As will appear later, however, stars close to the limiting magnitude are usually the only ones affected by classification errors of this kind. Such stars are generally omitted, and for simplicity the equation is given in the form actually used.

The discussion does not end with the solution for the relations which give the values of $\delta C$, $E$, and $C_s$. The residuals for individual stars obtained by substituting these quantities into equation (1) themselves involve statistical relationships which yield much useful information on the constancy of the zero point of the color indices, the uniformity of absorption in the obscuring cloud, the dispersion in color among stars of the same spectral class, and, finally, on the accidental errors of spectral classification.

## II. SOME DETAILS OF PROCEDURE

1. The spectral data used are as shown in the accompanying tabulation. Parkhurst's classifications, *Yerkes Actinometry* (YA),[7] for 23 F-type stars, Pv $m < 8.0$, were also used for a special purpose.

[3] The existence of a magnitude error in the color indices for stars of certain spectral types was stated in a supplementary note to the Introduction, *Polar Catalogue*, p. 49.

[4] F. H. Seares, *Mt. W. Comm.*, No. 119; *Proc. Nat. Acad.*, **22**, 327, 1936.

[5] *Mt. W. Contr.*, No. 650; *Ap. J.*, **94**, 215, 1941.

[6] The results from comparison stars for Eros (Ross and Zug, *A.N.*, **239**, 289, 1930; Seares, Sitterly, and Joyner, *Mt. W. Contr.*, No. 415; *Ap. J.*, **72**, 311, 1930) gave for the first time what appears to be the correct value of $C$, international system, for A0 stars in unobscured regions. For types G0 and later the mean colors were necessarily for a mixture of giants and dwarfs.

[7] *Ap. J.*, **36**, 169, 1912.

MW and Y types are from slit spectrograms and hence unlikely to be affected by any magnitude error. All the others are from objective-prism photographs and may be affected by such errors. It is noteworthy, however, that the classification limit for Bg is 2 mag. below the limit for the color indices.

U types are from four fields, each 6° square, centered at 0, 6, 12, and 18 hours R.A. and +85° Dec.; Bg, 3.5° square, covers Kapteyn's Selected Area 1. The other observations extend at random over the polar cap north of +80°.

The numbers of stars are those actually used to obtain $C_s$ (Table 7). Rejected stars are listed in the notes to the tables, especially Table 5. Some of these rejected stars reappear in the discussion of residuals.

| Source | Pv Limit | No. Stars | Symbol |
|---|---|---|---|
| Harvard, *H.D. Catalogue* | 9 | 548 | HD |
| Upsala, Petersson, *Medd. Astron. Obs.*, No. 29, 1927 | 11 | 847 | U |
| Bergedorf, Schwassmann, *Spektral-Durchmusterung*, **1**, 1935 | 13 | 171 | Bg |
| Mount Wilson, Adams and others, *Spectroscopic Catalogue*, *Contr.* No. 511, 1935 | 9 | 53 | MW |
| Yerkes, Keenan and Babcock, mostly HD A0 stars; *Ap. J.*, **93**, 64, 1941 | 9 | 53 | Y |

2. Owing to systematic differences between spectral classifications by different observers, a standard reference system is required. The HD has been used for this purpose, and all classifications from other sources have been reduced to this system. The systematic corrections required for this reduction and the mean accidental classification differences needed for the discussion of the residuals have been taken from the preceding *Mt. W. Contribution*.[8] The direct method is to correct the types of individual stars; but, since color indices are to be correlated with types, it is often more expeditious to discuss each series of observations relative to its own classification system and at the end reduce to the HD system by correcting the mean colors. The standard unit for spectral differences is the ordinary classification unit (0.1 spectral class), although the equivalent difference in $C$, expressed in units of 0.01 mag., is often needed.

3. The magnitudes used throughout are the photovisual values of the *Polar Catalogue*. Color indices and color excess $E$, as usual, are expressed in magnitudes, although 0.01 mag. is sometimes used for $E$. Systematic corrections, residuals, etc., for which the normal unit is the magnitude, are also frequently given in units of 0.01 mag., as the context will show.

4. Distances, in parsecs, unless otherwise noted, are the apparent photometric values obtained from the relation $\log \rho = 0.2\,(m - M) + 1$, in which $m$ is the observed photovisual magnitude, that is, uncorrected for absorption. Allowance for absorption is most conveniently made after $E$ has been determined as a function of the apparent distance. Since values of $M$ for individual stars are usually unknown, the mean $M$ for the type in question must be used. Those adopted for early-type stars, which agree closely with R. E. Wilson's[9] results (B0–5) from proper motions, are given in Table 1. From A3 on, H. N. Russell's values have been adopted.

5. From G0 on, the stars must be assigned to their respective luminosity classes—giants or dwarfs. The criterion used uniformly has been that provided by the color index and the spectral type. The normal excess of color in giants over dwarfs of the same type is enhanced by space absorption, which, of course, is greater for giants than for the rela-

[8] *Ap. J.*, **98**, 244, 1943.

[9] *Mt. W. Contr.*, No. 646; *Ap. J.*, **94**, 12, 1941.

tively near dwarfs. For most stars there was little doubt as to the designation, although frequently a decision could not be made until good approximations for the $E$ and $C_s$ relationships had become available. A number of borderline cases still remain in doubt, however, and for a few stars with types by different observers the results are contradictory because of classification errors. There is no conflict between the color-spectrum evidence and any of the Mount Wilson giant-dwarf designations (only 38 stars, however); and for Upsala, where the luminosity estimates were made from objective-prism spectrograms and extend to about the eleventh magnitude, there is agreement for about 84 per cent of the stars.

### III. EXISTENCE OF MAGNITUDE ERROR IN $C$

Consider, first, the behavior of the mean values of $C$ for magnitude groups of HD and U stars as shown in Tables 2 and 3, respectively. The characteristic feature is a decrease in $C$ with increasing $m$ for HD and for U A5 and F stars to $m = 8.5$. Elsewhere $C$ for U stars increases with $m$. This increase presumably originates in space absorption, the more probably so since the effect is less pronounced for dwarf stars than for the more distant giants. There is no a priori reason why the excess color of absorption should be-

TABLE 1*

MEAN ABSOLUTE MAGNITUDES FOR EARLY-TYPE STARS

| MW Sp | $M_{vis}$ | MW Sp | $M_{vis}$ | MW Sp | $M_{vis}$ | MW Sp | $M_{vis}$ | MW Sp | $M_{vis}$ | MW Sp | $M_{vis}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| B0... | −3.1 | B3... | −1.6 | B5.... | −0.9 | B8.... | 0.0 | A0... | +1.0 | A3.... | +1.7 |
| B1... | 2.6 | B4... | −1.2 | B6.... | .6 | B9.... | +0.4 | A1.... | 1.4 | A4.... | +1.7 |
| B2... | −2.2 | | | B7.... | −0.4 | | | A2.... | +1.6 | | |

* For other types see Russell, *Mt. W. Contr.*, No. 636, Table 12; *Ap. J.*, **92**, 354, 1940.

gin with the brightest stars, but in no case should an opposing change appear in the colors of normal stars. Apparently a magnitude error is superposed upon the absorption, but whether the error is in the values of $C$ or in the spectral types remains uncertain.

To proceed, we turn to spectral data which in all probability are free from any magnitude error—U types well above the classification limit and MW results from slit-spectrograms, using only a narrow spectral range in order that changes in $C_s$ (eq. [1]), may easily be allowed for. Further, we select stars within 100 parsecs' distance, since at this limit $E$ is known not to exceed 0.05 mag. The F stars are best suited to the purpose; they are numerous, their luminosities are moderate, and only rarely does one fall outside the main-sequence group. Neglecting $E$, we write equation (1) in the form

$$\delta C = C - C_s$$

and plot the values of $\delta C$ against $m$. Since only changes in $\delta C$ are of interest for the moment, the zero point of $C_s$ is unimportant. Both U and MW stars show a decrease in $\delta C$ of about 0.15 mag. in the interval $m = 5.0$–$8.5$, a change opposite to and in excess of the neglected absorption. To guard against the undue influence of accidental error on the values of $\delta C$ from the few MW stars, Dr. W. S. Adams kindly reclassified the original spectrograms, but without any significant change. Moreover, the 23 F stars from the *Yerkes Actinometry* give a similar result, all in confirmation of the general trend shown by the HD data in Table 2.

Incidentally, it may be noted that the means of $m$ for all the stars in each of the three groups—U, MW, and YA—differ considerably and that the respective mean $C$'s also differ by just the amounts to be expected from the variation in $\delta C$. This agreement checks the systematic reduction to the HD system.

In the face of this evidence it can scarcely be doubted that the F stars at least require a correction depending on magnitude and that the values of $\delta C$ are really to be associated with $C$, as the symbols suggest, and not with the spectral types. Examination of U stars between 100 and 200 parsecs, with an approximate correction for $E$, shows, however, that below the ninth magnitude the error apparently is negligible. Moreover, it appears that for stars covering a wide range in $m$ the values of $\delta C$ will have little influence on the calculation of mean values of $E$. We therefore turn to the absorption function, disregarding the magnitude error altogether for the present.

TABLE 2

MEAN COLOR INDEX AND MAGNITUDE—HARVARD SPECTRA

| $m$ | A | | F | | G | | K, M | | All | |
|---|---|---|---|---|---|---|---|---|---|---|
| <6.0 | +5* | 8 | +5 | 3 | 0 | 3 | + 5 | 14 | +5 | 28 |
| 6.5 | +2 | 20 | +8 | 11 | + 8 | 11 | + 3 | 23 | +4 | 65 |
| 7.5 | 0 | 35 | +3 | 43 | + 5 | 46 | + 1 | 70 | +2 | 194 |
| 8.5 | −3 | 51 | −3 | 71 | − 5 | 59 | − 1 | 79 | −3 | 260 |
| ⩾9.0 | +3 | 15 | −2 | 15 | −11 | 6 | −37 | 2 | −3 | 38 |
| All | −0.2 | 129 | −0.1 | 143 | − 0.3 | 125 | − 0.3 | 188 | −0.2 | 585 |

* Group mean *C minus* mean for all stars brighter than $m = 9.0$; unit = 0.01 mag. The number of stars in the group follows.

TABLE 3

MEAN COLOR INDEX AND MAGNITUDE—UPSALA SPECTRA

| $m$ | A5 | | F | | gG | | gK, M | | A5–gM | | dG, K | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| < 7.0 | +15 | 1 | + 5 | 9 | −15 | 1 | − 6 | 11 | − 1 | 22 | | |
| 7.5 | + 6 | 2 | + 2 | 16 | − 6 | 11 | −11 | 7 | − 3 | 36 | −2 | 15 |
| 8.5 | − 3 | 10 | − 1 | 42 | + 3 | 24 | + 5 | 32 | + 1 | 108 | +1 | 35 |
| 9.5 | +12 | 7 | +11 | 101 | +14 | 41 | +19 | 44 | +14 | 193 | +8 | 34 |
| 10.5 | +22 | 7 | +14 | 190 | +11 | 54 | + 9 | 28 | +13 | 279 | +5 | 107 |
| ⩾11.0 | | | +11 | 5 | | | | | +11 | 5 | +3 | 1 |
| ⩽ 9.0 | − 0.2 | 27* | + 0.3 | 363 | − 0.3 | 131 | + 0.1 | 122 | + 0.1 | 643 | +0.1 | 192 |

* Number for all magnitudes.

## IV. APPROXIMATIONS FOR THE ABSORPTION FUNCTION $E = R_1(\rho)$

Equation (1) accordingly takes the form

$$E = C - C_s .$$

Again we use F-type stars, 363 from the U series, 52 from Bg. As before, the zero point for $C_s$ is unimportant; we need only changes in $C_s$ within the narrow interval of the F's, which are easily found with sufficient accuracy from the observed colors.

The mean values of $E$ for a grouping according to distance are shown in Figure 1. The progression in $E$ from the two series of data is so nearly the same that we combine them, at the same time adjusting the zero point to give $E = 0$ at zero distance, and obtain the nearly linear relation shown at the bottom of the diagram. To a limit at about 400 parsecs we thus find

$$E = 0.00050\rho \text{ mag.} \qquad (2)$$

The zero-point adjustment for $E$, of course, automatically fixes the zero point for $C_s$. The latter, however, retains a small uncertainty, since there is doubt as to where the ab-

sorption begins. The neglected magnitude error can be traced in the residuals of the first two and the fourth points, but its influence is little in evidence. Owing to the luminosity range among the F's, each mean value of $E$ includes stars covering an interval of about 1.5 mag. The positive and negative values of $\delta C$ therefore largely compensate each other.

We now use the relation

$$\delta C = C - E - C_s \tag{3}$$

to calculate more accurate values of the magnitude error and then revise the values of $E$ accordingly. For this revision we include the remaining F stars (HD, MW), the A's (HD, U, Y), and the few available B's (HD, Y). In computing $\delta C$ for B- and A-type stars we are obliged to assume, as elsewhere, that the absorption function found from the F's also applies to other spectral classes. The data are not suited to the isolation of the slight dependence of absorption on stellar temperature.

The second approximation for $E$, based on 765 stars, is again to 400 parsecs a sensibly linear relation, with a coefficient of 0.00047, 6 per cent smaller than the original value.

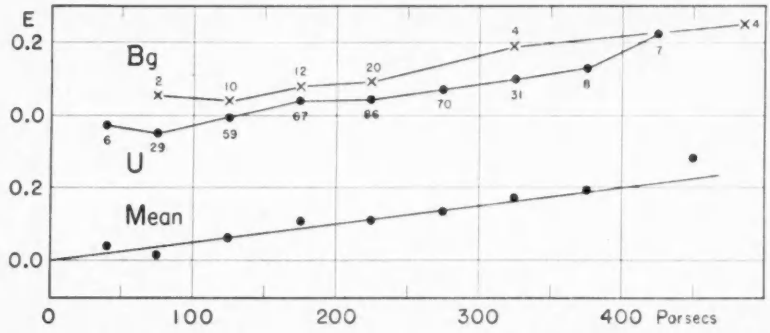



FIG. 1.—Color excess $E$ and apparent distance for F-type stars; 52 Bg spectra, 363 U. For the two upper curves the zero point is arbitrary; for the mean curve it is adjusted to give $E = 0$ at zero distance, an assumption necessary to fix the zero point of $C_S$.

The range in distance, however, has not been greatly increased, since the added stars of high luminosity are but rarely fainter than $m = 9$. Faint early-type stars of high luminosity occur among the U data, but the types are expressed in the notation of Lindblad and cannot be utilized at this stage of the reduction.

To extend the absorption function we must therefore use the apparently faint late-type giants of the U series. In principle we proceed as before, but with a simplification. Calculation of $\delta C$ from about 180 dwarf G and K stars shows that the magnitude error for these types is everywhere negligible ($m$ = 7–11); we may therefore disregard it for the giants. On the other hand, however, there is a complication. Most of these giants are so distant that an extrapolation of the calculated values of $E$ back to $\rho = 0$ is impracticable. Zero points must therefore be determined by comparisons with the segment of the absorption relation already established.

Details at this stage are of some importance, since apparently we are concerned with a maximum value of $E$. We group the color indices for each giant subtype from G5 to K5 according to distance and plot their mean values. The result is a roughly parallel series of curves showing the characteristic increase in color out to about 500 parsecs, where the curves flatten out. Since the data are too scanty for a separate discussion of the subtypes, we reduce them all to the zero point of the gG8 colors and deal with a mean curve.

Table 4 shows the reduced mean $C$ for each group, followed by the number of stars in the group. The constants for reduction to gG8 and the total numbers of stars are in the last line but one. The mean gG8-curve, which from about 600 parsecs on shows sensibly

constant values of $C$, is to be compared with the known segment of the absorption-curve ($E$, third column from the end). The differences in the last column but one are values of $C$ for gG8, U system, at zero distance. The second and third of these differences are affected by irregularities in some of the U K0–K5 data which operate as a magnitude error but bear no relation to the error found for other types. The mean of 0.90 mag. from the remaining 70 stars, subtracted from the mean values of $C$ for gG8, gives $E_g$, the absorption results from the U giants shown in the last column of the table. With two exceptions, they agree well with the relation already found and beyond 600 parsecs indicate a constant maximum $E$ of 0.28 mag. Combination of the values of $E$ and $E_g$ completes the second approximation for the absorption function, which now depends on 956 stars (strictly speaking, 956 spectral classifications, since the same star often occurs in different spectral series). Finally, in the last line of the table are the values of $C$ at zero distance, i.e., of $C_s$, for each of the subtypes. These are still to be reduced to the HD system.

TABLE 4

ABSORPTION-CURVE FROM G5–K5 GIANTS—UPSALA SPECTRA

| Mean $\rho$ | G5 | G8 | K0 | K2 | K5 | Mean (G8) | $E$ | G8 $\rho=0$ | $E_g$ |
|---|---|---|---|---|---|---|---|---|---|
| 52..... | 0.88 1 | ..... | ..... | ..... | ..... | 0.88 1 | 0.02 | 0.86 | −0.02 |
| 192..... | 0.97 4 | ..... | 0.89 5 | 0.97 6 | ..... | 0.94 15 | .09 | ( .85) | (+ .04) |
| 278..... | 1.07 2 | 0.98 6 | ..... | ..... | 0.97 4 | 0.99 12 | .13 | ( .86) | (+ .09) |
| 349..... | 1.06 6 | 1.07 6 | 0.93 4 | ..... | ..... | 1.03 16 | .16 | .87 | + .13 |
| 432..... | 1.09 6 | 1.15 9 | 1.17 4 | 1.04 5 | ..... | 1.11 24 | .20 | .91 | + .21 |
| 545..... | 1.13 7 | 1.17 7 | 1.25 5 | 1.17 4 | 1.10 6 | 1.16 29 | .26 | .90 | + .26 |
| 642..... | 1.21 10 | 1.19 7 | 1.12 11 | ..... | 1.24 4 | 1.18 32 | ..... | ..... | + .28 |
| 742..... | 1.14 10 | 1.20 9 | 1.22 6 | 1.24 5 | ..... | 1.19 30 | ..... | ..... | + .29 |
| 868..... | 1.20 6 | 1.14 5 | 1.20 8 | ..... | ..... | 1.18 19 | ..... | ..... | + .28 |
| 924..... | 1.19 4 | 1.16 8 | 1.20 7 | ..... | 1.23 5 | 1.19 24 | ..... | ..... | + .29 |
| 997..... | 1.06 6 | ..... | ..... | 1.08 5 | 1.20 5 | (1.11) 16 | ..... | ..... | (+0.21) |
| Const... | +0 11 62 | 0 00 57 | −0 12 50 | −0 32 25 | −0 58 24 | 1.18 218 | ..... | 0.90 | +0.28 |
| $C^*(\rho=0)$ | 0.79 | 0.90 | 1.02 | 1.22 | 1.48 | | | | |

* Later increased by 0.01 for final adjustment of zero point.

## V. MAGNITUDE ERROR IN $C$ AND CLASSIFICATION ERROR

The absorption relation from the preceding section is now to be used for a revision of the values of $\delta C$ and an extension of the calculation to other spectral types. At the same time the question of systematic classification errors requires further attention. Although $\delta C$ is defined as a magnitude error in $C$, its calculation from equation (3) automatically includes, through $C_s$, the influence of any systematic classification error (accidental errors are disregarded, although they provide an obtrusive complication whenever the group of stars used is small). The results collected in Table 5 and illustrated in Figure 2 therefore represent the combined effect of these two sources of error. The criterion for their separation is the agreement or disagreement of values of $\delta C$ found from different spectral series. The general accordance of the first three curve groups of Figure 2 thus reveals a clearly marked error in $C$ affecting stars of types earlier than G0 and of magnitudes brighter than about 9.0; but for fainter early-type stars and all G–M stars there is little indication of any discordance. Of systematic errors in type, on the other hand, there is little conspicuous evidence except near the classification limits—magnitudes 8.5–9.0 for HD and 10.5–11.0 for U. Exceptional points elsewhere are usually of low weight and thus suggest the influence of accidental error, although those for curve group 8, $m$ = 6.5–

TABLE 5

VALUES OF $\delta C$ FOR DIFFERENT TYPES AND MAGNITUDES

(Unit = 0.01 Mag.; Number of Stars in Parentheses)

HARVARD (HD)

| m | B | m | A | F | m | dG0 | m | dG5 | m | gG5 |
|---|---|---|---|---|---|---|---|---|---|---|
| | | 4.4 | + 5 (1) | | | | | | 4.4 | − 4 (1) |
| | | 5.6 | +10.2 (6) | + 6.3 (3) | 5.7 | +10 (1) | | | 5.5 | − 7 (1) |
| 6.0 | + 1.5 (2) | 6.3 | + 6.0 (8) | +10.7 (6) | | | | | 6.4 | + 5.8 (4) |
| | | 6.8 | + 1.7 (14) | + 2.2 (6) | | | 6.7 | + 1.0 (2) | | |
| | | 7.2 | + 0.5 (16) | + 6.7 (19) | 7.1 | + 6.0 (4) | | | 7.0 | + 2.2 (5) |
| 7.6 | − 0.2 (6) | 7.8 | − 3.0 (19) | − 3.0 (24) | 7.5 | + 3.0 (4) | 7.6 | − 1.8 (4) | 7.5 | − 2.6 (14) |
| 8.2 | − 5.0 (5) | 8.2 | − 7.6 (31) | − 6.1 (38) | 8.1 | − 2.2 (5) | 8.0 | + 4.0 (4) | 7.9 | − 1.2 (17) |
| | | 8.8 | − 8.9 (20) | − 8.4 (33) | 8.4 | − 5.5 (4) | 8.5 | − 2.2 (4) | 8.4 | + 2.1 (11) |
| | | 9.2 | − 6.6 (15) | − 5.8 (15) | 8.7 | −15.0 (9) | 8.8 | + 1.0 (4) | 8.8 | + 1.7 (8) |
| Total stars (13) | | | (130) | (144) | | (27) | | (18) | | (61) |

| HARVARD (HD) | | | | | | | | YA | | Y | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| m | dK0 | m | gK0 | m | K2, 5 | m | Ma, b | m | F | m | B, A |
| | | 4.5 | + 5.5 (2) | | | | | | | | |
| | | 5.4 | 0.0 (4) | 5.4 | + 4.7 (3) | 5.0 | + 8.5 (2) | | | 5.4 | +11.2 (4) |
| | | 6.0 | + 0.2 (6) | | | | | 5.8 | + 6.0 (2) | 6.3 | + 9.2 (4) |
| 6.6 | 0.0 (4) | 6.7 | − 0.9 (7) | 6.9 | + 3.3 (3) | 6.6 | − 3.8 (5) | 6.4 | + 5.6 (5) | 6.7 | + 0.9 (7) |
| 7.2 | + 0.2 (8) | 7.2 | + 4.2 (12) | | | | | 7.0 | + 5.0 (7) | 7.3 | + 1.7 (7) |
| 7.6 | + 0.6 (7) | | | 7.5 | + 1.5 (15) | | | 7.3 | + 3.8 (8) | | |
| 7.9 | − 1.9 (7) | 7.8 | − 0.3 (14) | | | | | 7.8 | − 4 (1) | 7.7 | − 0.1 (11) |
| 8.2 | − 4.1 (8) | 8.2 | − 5.8 (13) | 8.2 | − 1.2 (12) | 8.2 | + 0.9 (7) | | | 8.1 | − 5.9 (11) |
| 8.4 | + 4.0 (6) | 8.5 | + 1.9 (7) | 8.6 | − 3.9 (8) | | | | | 8.9 | −12.3 (3) |
| 8.8 | − 0.8 (6) | 8.7 | −17.2 (4) | | | | | | | 9.2 | −12.4 (5) |
| Total stars (46) | | | (69) | | (41) | | (14) | | (23) | | (52) |

UPSALA (U)

| m | A5 | m | F | m | dG, dK | m | gG5, 8 | m | gK0 | m | gK2, 5 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 4.4 | − 5 (1) | 4.3 | +13 (1) | | |
| 5.5 | +11 (1) | | | | | | | | | 5.1 | + 6.3 (3) |
| | | 6.4 | + 2.6 (5) | | | | | 6.4 | − 7.0 (2) | 6.4 | −10.5 (2) |
| 7.3 | + 2.5 (2) | 7.2 | + 3.0 (7) | 7.2 | + 0.2 (9) | | | 7.1 | − 8 (1) | | |
| | | 7.8 | − 3.0 (12) | 7.8 | − 0.5 (9) | 7.5 | − 0.5 (10) | | | 7.5 | − 9.0 (4) |
| | | 8.1 | − 7.7 (14) | 8.2 | − 0.6 (18) | 8.3 | − 0.1 (7) | 8.0 | − 7 (1) | 8.2 | − 3.4 (8) |
| 8.4 | + 0.4 (5) | 8.5 | − 5.1 (13) | | | | | | | | |
| 8.8 | − 5.8 (6) | 8.9 | − 3.9 (22) | 8.8 | + 1.1 (15) | 8.7 | + 0.7 (17) | 8.8 | + 3.5 (4) | 8.7 | + 1.8 (9) |
| | | 9.2 | + 4.4 (33) | 9.2 | + 1.6 (17) | 9.2 | − 2.2 (13) | 9.2 | + 1.0 (9) | 9.2 | + 5.8 (5) |
| 9.6 | + 0.2 (6) | 9.6 | + 2.5 (29) | | | 9.7 | − 1.0 (27) | 9.7 | 0.0 (9) | | |
| | | 9.9 | + 1.3 (33) | 9.8 | + 2.3 (16) | | | | | 9.8 | + 2.5 (10) |
| 10.2 | − 5 (1) | 10.2 | − 0.7 (34) | 10.2 | − 1.0 (43) | 10.2 | + 0.3 (33) | 10.2 | + 1.4 (15) | 10.3 | −10.8 (6) |
| 10.4 | + 4.5 (4) | 10.5 | − 0.8 (94) | | | | | | | | |
| 10.8 | 0.0 (2) | 10.9 | + 1.5 (67) | 10.8 | − 4.9 (57) | 10.7 | − 7.5 (26) | | | | |
| Total stars (27) | | | (363) | | (184) | | (134) | | (42) | | (47) |

| BERGEDORF (Bg) | | | | | | MOUNT WILSON (MW) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| m | A, F | m | d, gG | m | d, gK | m | F | m | dG | m | gG, gK |
| | | | | | | | | | | 4.5 | + 3.4 (5) |
| | | | | 5.1 | − 2 (1) | 5.5 | + 9.0 (2) | | | 5.6 | + 3.0 (8) |
| 6.4 | + 4.0 (2) | 6.6 | + 6 (1) | | | 6.4 | + 8.8 (6) | 6.1 | + 2.0 (2) | 6.6 | + 1.0 (10) |
| 7.3 | + 0.5 (2) | | | 7.5 | −13 (1) | 7.2 | + 2.6 (5) | 7.4 | − 3.0 (2) | | |
| | | 7.8 | + 4 (1) | | | | | | | 7.7 | + 5.5 (2) |
| 8.2 | − 5.5 (2) | 8.3 | − 2.5 (4) | | | | | | | | |
| 8.8 | − 7.0 (7) | 8.7 | −10.0 (2) | 8.6 | − 1.0 (2) | 8.7 | −10 (1) | 8.7 | −5.3 (3) | | |
| 9.2 | + 2.6 (9) | 9.2 | − 3.1 (9) | 9.3 | + 2.7 (3) | | | | | | |
| 9.8 | + 1.6 (14) | 9.8 | + 4.9 (10) | 9.8 | + 0.3 (3) | | | | | | |
| 10.2 | − 2.9 (19) | 10.2 | − 2.8 (27) | 10.4 | − 3.5 (2) | | | | | | |
| 10.8 | + 6.4 (9) | 10.8 | + 0.7 (31) | 10.7 | − 0.5 (2) | | | | | | |
| 11.2 | − 5 (1) | 11.2 | − 0.3 (3) | | | | | | | | |
| 12.4 | − 5.0 (2) | 12.0 | − 0.7 (3) | | | | | | | | |
| Total stars (67) | | | (91) | | (14) | | (14) | | (7) | | (25) |

## NOTES TO TABLE 5

HD A, F None of the 287 HD early-type stars has been rejected.

HD G0 BD 84°9, rejected. The observed $C$, 0.15, agrees with the U classification F2. BD 80°344, 81°362, 81°412, and 83°236 are giants, the remaining 27 stars, dwarfs. The low mean $C$ ($v = -0.15$) for the 9 stars with $m > 8.5$ suggests the presence of a considerable number of F's. Three of them have U classifications F8, dG0, and F5.

HD G5 The accepted dwarfs are:

| | | | | |
|---|---|---|---|---|
| BD 80°238 | 81°178 | 83°172 | 85° 75 | 85°390 |
| 409 | 194 | 527 | 214 | 400 |
| 614 | 482 | 84 163 | 330 | 87 99 |
| | 742 | 311 | 347 | |

Ten others, $m \lesssim 8.5$, were rejected, namely:

| | | | |
|---|---|---|---|
| BD 80°241 | 82°689 | 84° 42 | 86°14 |
| 575 | 83 505 | 85 355 | 65 |
| 766 | | | 96 |

The values of $C$ range from 0.25 to 0.51 and for type dG5 give a mean $v$ (with allowance for absorption) of $-0.32$ mag., far in excess of any error in $C$. The remaining 64 stars are giants. Three of them—BD 80°395, 83°603, and 86°79—were rejected, however. Their colors agree with the G8–K2 types found by other observers.

HD K0 From 73 giants, 4 were rejected: BD 84°152, 85°80, 87°41, 89°22; all K2 or later, according to other observers, in agreement with the large values of $C$. The giant character of the 73 stars is confirmed by U for 21, by MW for 14 (5 dupl.). Nine dwarfs were rejected, most of them close to the magnitude limit of the HD, namely:

| | | | | |
|---|---|---|---|---|
| BD 80° 3 | 81° 23 | 83° 441 | 85° 9 | 88° 2 |
| 606 | 832 | | 161 | 105 |

Other classifications for 5 of them are dG0 (1), dG5 (3), dK0 (1). $C$ for all 9 is small, giving a mean $v$ of $-0.26$. The 46 accepted dwarfs are:

| | | | | | |
|---|---|---|---|---|---|
| BD 80°127 | 81°517 | 82°132 | 83°177 | 84°274* | 86°172 |
| 230 | 541 | 518* | 178 | 461 | 87 23* |
| 604 | 736 | 543 | 232 | 509 | 85 |
| 652 | 788 | 598 | 287 | 513 | 118 |
| 778 | 789 | 682 | 594 | 536 | 88 90 |
| 81 134 | 801 | 707 | 620 | 85 183 | 114 |
| 210 | 816 | 83 114* | 84 10 | 249 | |
| 295 | 82 51 | 144 | 14 | 263 | |

U classifications of 19 of these stars include 4 gG5, 9 gG8, 1 dG8, 4 gK0, 1 dK2—in all 17 giants and 2 dwarfs. Two others have Bg types, g:G5 and d::G8. The colors are in harmony with giant characteristics for 4 of the 5 gG5 types (marked with an asterisk), but the remaining 14 stars classed as giants at U are treated as dwarfs in discussing the U data (see below), as they are here.

In view of the limiting magnitude of the HD, the large ratio of dwarfs to giants, 46 to 69, thus found for the K0 stars, is questionable and suggests classification errors. The exclusion of the doubtful stars would not, however, change the mean $C$.

HD K2, 5 The rejected stars are

| | | | |
|---|---|---|---|
| K2 | BD 80°607 | K5 | BD 83°452 |
| | 81 302 | | 87 104 |
| | 82 704 | | |

Remaining are 24 gK2 (of which 9 are classified at U, all as giants), 5 dK2, and 12 gK5. The dK2 stars are BD 81°810, 82°224, 472, 85°398, and 87°187.

HD M The 14 stars (12 Ma, 2 Mb) are all treated as giants. For 8 of them there is confirmation by U and MW.

YA F BD 86°193, F5p is rejected.

Y B, A All stars for which $C$ is available were used.

U A5 The values of $\delta C$ follow the mean curve for F-type stars, a fact best shown by subtracting the ordinates of this curve (the only series in Table 5 which has been so corrected).

U F The clearly marked run in $\delta C$ is shown by each of the subtypes F0, F2, F5, and F8. No F-type star has been rejected.

U G, K From a total of 431 stars, 12 have been rejected, most of them probably wrong classifications:

| BD | $v$ | BD | $v$ | BD | $v$ |
|---|---|---|---|---|---|
| gG8 85°207 | +0.37 | gK0 83°484 | +0.29 | dK0 85° 9 | −0.28 |
| 381 | .37 | 521 | + .35 | 291 | − .46 |
| 395 | .25 | 85 6 | + .50 | gK2 82 504 | + .39 |
| 86 59 | +0.27 | 86 174 | −0.20 | gK5 185 | −0.35 |

The last star, 82°185, the only one bright enough to be in the *H.D.*, is there listed as K2, which would give a $v$ of $-0.05$ mag. Some of the positive residuals, however, may indicate instances of unusual color excess.

Of the 419 stars used, the U giant and dwarf designations have been changed for 65, as shown in the accompanying tabulation which gives the adopted grouping.

For 13 stars (below the main tabulation) the changes are borderline cases and doubtful, as indicated by the alternative residuals. In the main, however, the agreement has been much improved. The resulting SD relative to the adopted mean spectrum-color relation is usually very much smaller than $SD_v$, the difference corresponding to the U designation. The AD is also much reduced, to a mean of about $\pm 0.06$ mag., which includes the errors from all sources. Nevertheless, as explained in the text, it must be recognized that some of the inconsistencies which have been removed by changing the designations probably originate in errors in the types. Several of the changes were made during the preparation of Table 9 (see notes to that table). The data for gK0 and gK2, 5 in Table 5 have been revised accordingly. The other data in Table 5, for which the changes are unimportant, and all the curves in Figure 2 remain in their original form.

NOTES TO TABLE 5—*Continued*

| | gG0 | gG5 | dG5 | gG8 | dG8 | dK0 | dK2 | dK5 |
|---|---|---|---|---|---|---|---|---|
| | 84°248 | 87°153 | 83°118 | 82°529 | 81°789 | 82°542 | 82°140 | 82°185 |
| | 295 | | 147 | 85 290 | 82 132 | 707 | 353 | 83 664 |
| | 85 218 | | 84 135 | | 527 | 728 | 85 112 | 86 179 |
| | 87 2 | | 539 | | 696 | 83 25 | 398 | 323 |
| | 159 | | 85 90 | | 735 | 144 | 86 89 | 87 88 |
| | | | 306 | | 83 178 | 672 | 196 | |
| | | | 385 | | 179 | 84 513 | 253 | |
| | | | 400 | | 336 | 536 | 284 | |
| | | | 86 53 | | 84 10 | 85 166 | | |
| | | | 135 | | 14 | 175 | | |
| | | | 172 | | 110 | 216 | | |
| | | | 87 170 | | 509 | 276 | | |
| | | | | | 85 183 | 86 145 | | |
| | | | | | 195 | 174 | | |
| | | | | | 292 | 87 104 | | |
| | | | | | 87 85 | | | |
| | | | | | 103 | | | |
| $SD_v$.... | +0.30 | +0.22 | −0.26 | +0.22 | −0.25 | −0.25 | −0.41 | −0.40 |
| SD.... | −0.030 | −0.11 | +0.029 | −0.100 | 0.000 | +0.049 | +0.046 | +0.004 |
| AD.... | ±0.052 | ..... | ±0.063 | ±0.100 | ±0.047 | ±0.065 | ±0.071 | ±0.064 |

DOUBTFUL DESIGNATIONS AND ALTERNATIVE RESIDUALS

| BD | Sp | Dwarf | Giant | BD | Sp | Dwarf | Giant |
|---|---|---|---|---|---|---|---|
| 82°126..... | K2 | +0.22 | −0.25 | 85° 7..... | K0 | +0.18 | −0.19 |
| 162..... | K0 | + .16 | .20 | 109..... | G8 | − .26 | .57(dG5?) |
| 342..... | G8 | + .09 | .13 | 316..... | G5 | + .15 | .19 |
| 533..... | G5 | + .17 | .16 | 86 117..... | K0 | + .17 | .19 |
| 543..... | G8 | + .11 | .13 | 87 133..... | G5 | + .15 | .18 |
| 83 129..... | G8 | + .11 | .15 | 166..... | K0 | +0.18 | −0.19 |
| 84 23..... | K0 | −0.19 | −0.52(dG5–8?) | | | | |

Bg A, F 15 and 52 stars, respectively. No rejections.

Bg G0 17 stars, of which only BD 87°57 is a giant.

Bg G1 10 stars. Only BD 87°87 and 89°5 are giants.

Bg G2 15 stars. The giants are BD 88°34, 88°40, and 88°56. The first is doubtful, $v$ being −0.22 (giant) and +0.26 (dwarf).

Bg G3 5 stars. BD 88°50 and 88°142 are giants.

Bg G4 6 stars of which BD 88°18, 88°45, and 88°58 are dwarfs. The first is doubtful; $v$, +0.19 and −0.23 mag.

Bg G5 13 stars. BD 88°2, 89°15, and 89°34 are dwarfs. The giant BD 89°8 is doubtful; $v$, −0.20 and +0.21 mag.

Bg G6 5 stars. BD 88°5 and 89°20 are dwarfs, the latter doubtful; $v$, +0.17 and −0.19 mag.

Bg G7 3 stars, all giants.

Bg G8 20 stars. The 10 giants are

| | | | | |
|---|---|---|---|---|
| BD 86°79 | 87°14 | 88°12* | 88°19* | 88°44 |
| 87 8 | 87 79 | 88 14 | 88 31* | 89 9 |

The three marked with asterisks, giving residuals of +0.4 mag. or more, were rejected. The values of $C$ are well determined and of high weight. Unless the color excess is abnormal, the types are probably gK5. BD 87°46, 87°83, and 87°86, here accepted as dwarfs, have the U type gG5 and were used as giants in discussing the U data.

Bg K0 2 stars. BD 88°89 is used as a giant; a doubtful case, $v$ being −0.18 and +0.21 mag.

Bg K2 9 stars. BD 87°91 and 89°16 are dwarfs. The giant BD 87°41, $v$ +0.44, was rejected, as was done for the HD data where the type is K0. The U classification is gK5. The unusual color index, 1.94, is of high weight.

Bg K3 1 star, BD 87°88, a dwarf; $v$, +0.17 mag. For U, however, gK5 was used.

Bg K4 1 star, BD 88°17, a giant; $v$, +0.10 mag.

Bg K5 1 star, BD 89°22, (NPS 5r) a giant; $v$, −0.13 mag.

Bg K8 1 star, BD 87°51, (NPS 1r) a giant; $v$, −0.08 mag. The agreement between the colors and the Bg giant-dwarf designations is usually poor.

MW A–M 54 stars; 2 A's and 5 M's not used for $\delta C$. The dK0 BD 87°99 also omitted; $v$, −0.17 mag. Other classifications are U dG5, HD G5. The type (MW system) agreeing with the color (ME ± 0.02) would be dG4. The colors throughout are in harmony with the MW giant-dwarf designations.

8.5, involving only a few stars, are definitely systematic. This, in outline, is the general result. Certain details not covered by the notes to Table 5 should now be explained.

As already noted, the segregation of giants and dwarfs has been based on the observed color indices, corrected for absorption. Individual giants and dwarfs are listed in the notes for the smaller luminosity group of any series, for example, the accepted dwarfs among the HD K0 stars; the more numerous K0 giants can be identified by exclusion.

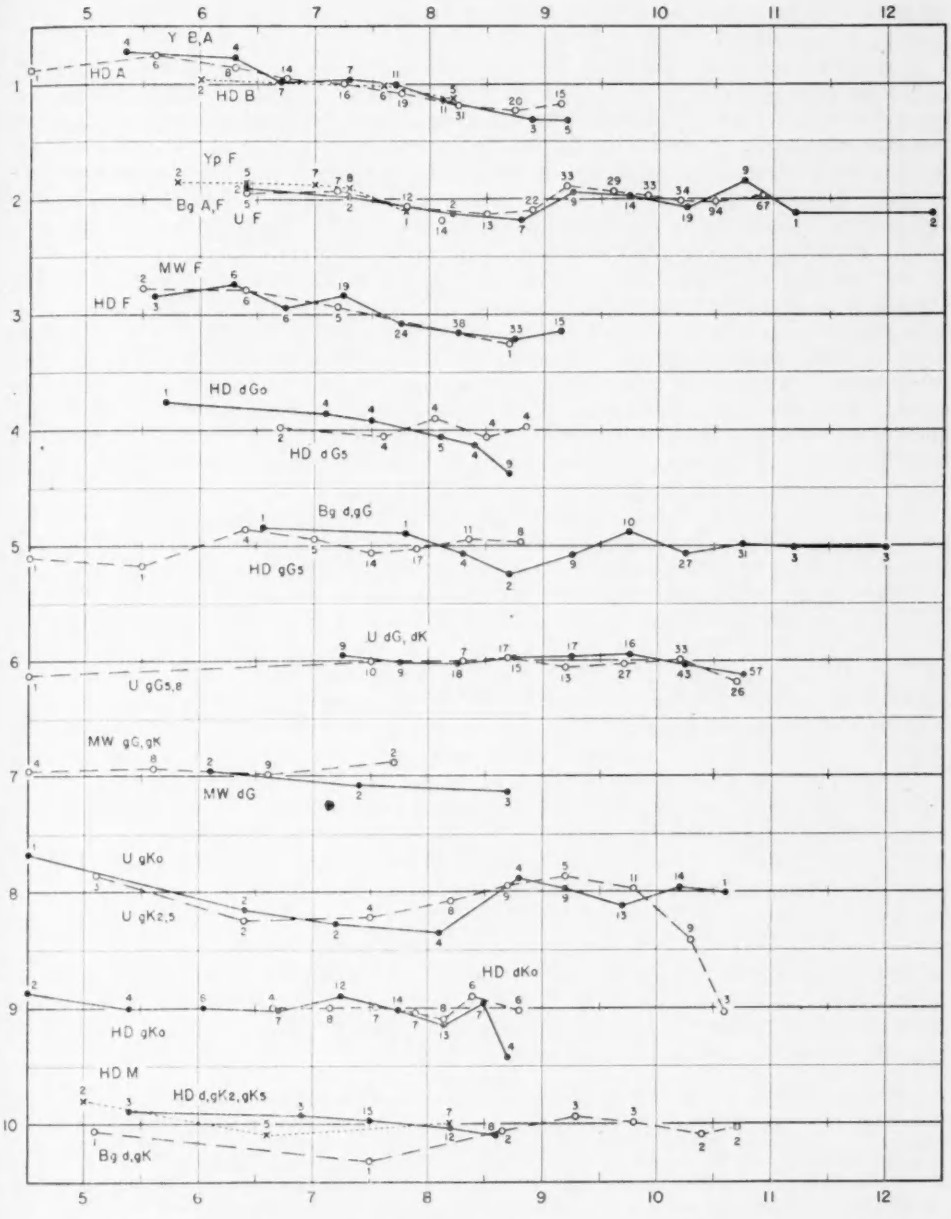



FIG. 2.—The ordinates (interval between horizontal lines = 0.2 mag.) of the curves are values of $\delta C = C - E - C_S$, which thus include the combined influence of errors in $C$ and in the spectral type used to obtain $C_S$, and of any deviation from the mean color excess $E$; plotted against Pv $m$. Figures indicate numbers of stars. The results for the several spectral series shown in the first three curve groups define the magnitude error in $C$ for types earlier than G0. For other types $C$ is not affected by any important systematic error. See Figure 3.

Since the U designations usually agree with the evidence from the colors, only changes in designation have been noted.

Unqualified statements that such and such stars are giants (or dwarfs) are contingent, since they disregard several sources of error—color indices, spectral types, distances of the stars, and any deviations from the mean absorption function. Classification errors thus sometimes lead to conflicting designations. For example, BD 84°274 is U gG5. Its color (with allowance for reduction to the HD system) indicates a giant, in harmony with the U classification. The HD type, however, is K0, which, in association with the observed color, puts the star into the dwarf list for HD data. Such conflicts are ignored, as they must be, if an invidious selection in residuals is to be avoided.

Since the classification errors of faint stars have often been in doubt, certain late-type U stars noted as giants have perhaps been wrongly changed to dwarfs in order to avoid a large negative $\delta C$. The relatively large number of such changes (see Notes) is a suspicious circumstance. On the other hand, the large negative discordance for faint U gK2, 5 stars, curve group 8, may be partly due to a few erroneous designations that could not be corrected. Since the U list includes no dK5 designations, the normal $C$ for this type is unknown, and changes from giants to dwarfs become uncertain. These ambiguous cases have little influence on the question of magnitude error in $C$, but they do complicate decisions as to the presence of systematic classification errors.

The accuracy of the U giant-dwarf designations appears to be high for objective-prism spectrograms. With 13 doubtful stars excluded, 65 of the designations for 419 stars of types G0 or later have been changed. The evidence from the colors, as already remarked, therefore agrees with that from the spectra for about 84 per cent of the U G–M stars.

When grouped according to distance, the *Catalogue* colors of B and A stars of the HD and Y lists show no certain progressive change in their mean values; the magnitude error in $C$ neutralizes the color excess,[10] and without other data the solution for $E$ by means of equation (3) would have been indeterminate. This circumstance raises a question as to whether the calculated absorption has been seriously affected by any error still hidden in $C$.

The accepted $\delta C$ for B and early A stars, at least, can be checked by the photoelectric colors of Stebbins, Huffer, and Whitford,[5] who have observed all the Y stars. These measurements are on the $C_1$ scale of Stebbins; and, since the spectral range is short—about B8–A4—we may safely assume a linear relation between $C$ and $C_1$. From the 52 stars observed in common we find

$$C = 2.1C_1 - 0.02 \, . \qquad (4)$$

With this relation[11] we may compute from $C_1$ for each star a value of its color $C_c$ on the international scale. Accidental errors in $C_1$, of course, will be carried over into $C_c$; but since $C_1$ is undoubtedly free from any progressive error, the differences $C - C_c$, grouped according to $m$, should reveal the magnitude error $\delta C$.

[10] E. G. Martin (*M.N.*, **102**, 261, 1942) has been misled by this circumstance. Apparently he has overlooked the note appended to the Introduction to the *Polar Catalogue*, calling attention to the fact that the color indices for certain spectral types are not independent of the magnitude and is thus led to suggest that the obscuration in the polar region is less than had been supposed. His question as to the accuracy of the color index for the A0 types among the comparison stars for Eros is answered by the confirmatory evidence of the present investigation. When freed from absorption by the relation found here, the polar stars give for A0 the same result as was found from the Eros stars. See next section.

[11] The value 1.5 sometimes used for the ratio $C/C_1$ is an average based on the spectral range A0–K0. The larger value indicated by equation (4) arises partly from the nonlinear relationship involved and applies only to early-type stars. *Note added October 12, 1943.*—Equation (4), from a graphical solution, is accurate enough for the present purpose. For more exacting comparisons of early-type stars, it should be replaced by the least-squares relation

$$\left.\begin{array}{l} C = 1.90\ C_1 - 0.023, \\ \pm 0.18 \quad \pm 0.008\ \text{ME.} \end{array}\right\} \qquad (4a)$$

The result thus found is essentially that shown for Y in curve group 1 (Fig. 2), the only noteworthy difference being a reduction of 0.06 mag. in the values for the first two points. Points in Figure 2, however, are affected by spectral peculiarities, which have little or no influence on equation (4). The differences in question merely indicate that both $C$ and $C_1$ are high for the types assigned. In fact, the spectra of 2 of the 8 stars are recognized as peculiar and were omitted by Stebbins from his discussion of the data. The magnitude error in $C_1$ complicates the solution for the constants in equation (4), and those given are from a second approximation.

The values of $\delta C$ for early-type stars are thus confirmed to $m = 9$ and in combination with the Y types give $E = 0.00045\ \rho$, differing only two units in the last decimal from the second approximation for the absorption function. To 400 parsecs, at least, the absorption is therefore well determined. This conclusion in turn checks the values of $\delta C$ to $m = 11$ for the F's and the late-type dwarfs, which, with minor exceptions, are all within the 400-parsec limit. The only remaining detail is $\delta C$ for late-type giants lying beyond 400 parsecs, that is, for stars which are mostly fainter than $m = 9.0$. For dwarfs beyond this limit, as elsewhere, $\delta C$ is sensibly zero, and we may reasonably suppose that

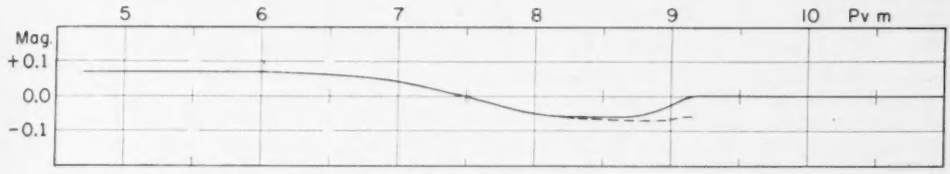



FIG. 3.—Magnitude error in color index; for spectral types earlier than G0. Ordinates of the curve are to be subtracted from the *Catalogue C*. The broken-line segment is to be used for HD (A, F) and Y (B, A) types. For G–M stars the correction is zero.

it is also zero for the giants, since the colors of giants and dwarfs are approximately the same. Although this assumption underlies the extension of the absorption function given in Table 4, it is unlikely that the result is in any wise seriously affected.

These details bring us back to the conclusions in respect to magnitude error in $C$ summarized in the first paragraph of this section, which must now be given a numerical expression. Any real systematic error in $C$, in the nature of the case, must change smoothly with the magnitude. On the other hand, minor differences in the curves of Figure 2 in many instances can well represent the influence of errors in the types. It is desirable, therefore, that the relation finally adopted for $\delta C$ be as simple as possible. That used for the further discussion of stars with types earlier than G0 is illustrated in Figure 3, in which the lower branch applies to the Y series of early-type stars and the HD A's and F's. The upper branch, whose ordinates range from +0.07 mag. for bright stars to −0.06 mag. at 8.5, is used for all the other types earlier than G0. The ordinates of the curve are to be subtracted from the observed color indices of the *Polar Catalogue*. Stars with types G0 and later receive no correction whatever.

Presumably some sort of transition occurs between the late F's and the early G's, but the data give little evidence of any gradual change in the correction, and no interpolation for intermediate values has been attempted. The best evidence for the applicability of these corrections is to be seen in the generally small deviations from the mean absorption function shown by groups of stars of widely different types and luminosities (see Table 10).

The classification errors indicated by Figure 2, when reasonably certain, have been allowed for—notably for U stars fainter than 10.5 of types dG, dK, and gG5, 8. To avoid the influence on later results of errors obviously present but uncertain in amount, some additional stars have been omitted, as explained in the notes to the tables concerned.

## VI. COLOR INDEX AND SPECTRUM

The values of $C_s$, as already explained, appear during the calculation of the absorption function (see, e.g., Table 4). Results for U, MW, and Bg subtypes, relative to their own classification systems, are given in Table 6. Those for U and MW are to be reduced

TABLE 6

COLOR INDEX AND SPECTRUM FOR U, MW, AND Bg TYPES
(Numbers of Stars in Parentheses)

| Sp | U | | MW | | Bg | | Bg−HD | |
|---|---|---|---|---|---|---|---|---|
| B9 | | | | | −0.34 (1) | | | |
| A0 | | | | | −0.15 (1) | | | |
| 1 | | | | | −0.10 (1) | | | |
| 2 | | | | | +0.01 (3) | | | |
| 3 | | | | | −0.03 (3) | | | |
| 4 | | | −0.13 (1) | | | | | |
| 5 | +0.00 (27) | | | | −0.08 (2) | | −0.01 | |
| 6 | | | + .04 (1) | | | | | |
| 8 | | | | | +0.04 (2) | | −0.03 | |
| 9 | | | | | +0.05 (2) | | − .02 | |
| F0 | 0.10 (26) | | + .17 (3) | | +0.14 (3) | | + .01 | |
| 1 | | | + .22 (2) | | | | | |
| 2 | 0.14 (48) | | + .12 (2) | | +0.18 (10) | | + .01 | |
| 3 | | | + .20 (1) | | +0.21 (2) | | .00 | |
| 4 | | | | | +0.16 (2) | | − .02 | |
| 5 | 0.28 (134) | | + .28 (1) | | +0.20 (4) | | − .03 | |
| 6 | | | + .37 (2) | | +0.24 (4) | | − .05 | |
| 7 | | | + .34 (1) | | +0.24 (3) | | − .07 | |
| 8 | 0.38 (155) | | + .36 (1) | | +0.27 (15) | | − .08 | |
| 9 | | | + .42 (1) | | +0.31 (9) | | − .09 | |
| G0 | 0.49 (75) | 0.61 (5) | + .53 (1) | 0.62 (1) | +0.32 (16) | 0.58 (1) | − .10 | +0.02 |
| 1 | | | | 0.74 (1) | +0.39 (8) | 0.71 (2) | − .08 | + .03 |
| 2 | | | + .41 (1) | | +0.42 (12) | 0.71 (3) | − .06 | + .04 |
| 3 | | | + .58 (1) | | +0.50 (3) | 0.73 (2) | − .04 | + .05 |
| 4 | | | + .50 (2) | 0.78 (3) | +0.66 (3) | 0.81 (3) | − .01 | + .06 |
| 5 | 0.67 (47) | 0.80 (62) | + .58 (1) | 0.80 (1) | +0.65 (3) | 0.85 (10) | .00 | + .07 |
| 6 | | | | 0.97 (2) | +0.74 (2) | 0.75 (3) | + .04 | + .07 |
| 7 | | | | 0.84 (1) | | 0.96 (3) | | + .08 |
| 8 | 0.82 (29) | 0.91 (57) | + .66 (1) | 0.93 (2) | +0.89 (10) | 0.97 (7) | + .08 | + .08 |
| 9 | | | | 0.83 (1) | | | | |
| K0 | 0.91 (23) | 1.03 (50) | +0.57 (1) | 1.02 (2) | +0.90 (1) | 0.96 (1) | + .08 | + .08 |
| 1 | | | | 0.96 (2) | | | | |
| 2 | +1.00 (10) | 1.23 (25) | | 1.06 (3) | +1.06 (2) | 1.34 (6) | + .07 | + .07 |
| 3 | | | | 1.24 (2) | +1.28 (1) | | +0.05 | |
| 4 | | | | 1.19 (1) | | 1.55 (1) | | + .04 |
| 5 | | 1.49 (24)* | | 1.50 (3) | | 1.39 (1) | | + .02 |
| 6 | | | | 1.44 (1)† | | | | |
| 8 | | 1.50 (12)* | | 1.56 (1) | | 1.48 (1) | | 0.00 |
| 10 | | | | 1.49 (3) | | | | |

* These stars are not included in Table 7, since they cannot be reduced to the HD system with any certainty. The spectral correction to U gK5 found in *Mt. W. Contr.*, No. 683, Table 6, is −3 classification units (only 8 stars), which would make $C$ seriously discordant. For U gK8 there is no indication whatever as to the required correction.

† gK6 = MW gM0.

to the HD system with the aid of the systematic spectral differences given in the preceding *Contribution*.[8] The Bg data required special treatment, owing to the uncertain relation of the classification system to the HD standard. In fact, the reduction used was obtained directly from the colors after a good approximation for $C_s$ on the HD system had become available. A plot of the Bg − HD differences in color, corrected for magnitude

error and absorption, led to the smoothed values given in the last column of Table 6, which meet the present requirement. Transformed into equivalent spectral differences, they also appear in the last column of Table 12 of the preceding *Contribution*.

The reduced values of $C_s$ from the U, the MW, and the Bg series, along with those from the HD itself, are given in Table 7 in the form of deviations from the adopted mean $C_s$ in the second column. This table also gives deviations for 180 Eros comparison stars, which will be considered in a moment, and for the 52 Y stars, which do not appear in Table 6 because the reduction to the HD system is very simple—a constant correction of $-1$ unit applied to the Y types.

The values of $C_s$ in the second column are the ordinates of the curve defined by the HD types and the weighted mean colors (deviations in third column) based on all the data. A few isolated values, for example, the MW color for A4, have been reduced to an adjacent subtype for combination with other data. The weighted mean color itself, or the mean for any component series, may be recovered by adding the appropriate deviation to the adopted $C_s$. The results are illustrated in Figure 4, the weighted means (the discordant isolated value for dK3 is omitted) and the resulting curve, above; the deviations for the component series, below.

The adopted values of $C_s$ correspond to an absorption beginning at zero distance. Since, according to Table 11, the boundary of the cloud cannot be more than 33 parsecs away, the possible zero-point correction to $C_s$ does not exceed $+0.02$ mag.

Neither the algebraic mean deviations (SD, unweighted) at the bottom of Table 7 nor the plots in Figure 4 reveal any important systematic differences. The zero-point deviation of 0.02 mag. for both MW and U giants corresponds to only 0.2 of a classification unit. The reduction of the data to the HD system seems therefore to be satisfactory.

The colors for the Eros stars, from an entirely different investigation,[12] are included, not because they contribute greatly to the spectrum-color relation, but because they check the reduction of the polar stars, and especially the magnitude and absorption corrections. The derivation of these color indices required a transfer of the color system of the Polar Sequence, located in an obscured region, to apparently unobscured stars in distant fields. In fact, it was these observations, together with the similar series by Ross and Zug,[6] which first revealed the presence of selective absorption in the polar region. HD A0 stars at the pole were thus found to be about 0.1 mag. redder than those in the Eros fields. Freed from absorption, the A0 polar stars now agree with the unobscured stars to 0.01 mag.[10] The obvious run in the deviations for the Eros stars may be due to an error in the color equation of the 10-inch Cooke refractor, which could not be well determined when the observations were reduced. The types used are Harvard values; but since they are rarely from the HD itself, classification differences may also play a part, as they sometimes do in HD extensions to fainter stars.[13]

It should be remembered that the values of $C_s$ in Table 7, final for the present paper, have been obtained with an absorption function which is an average for all types (temperatures). High-temperature stars therefore remain slightly undercorrected, low-temperature stars overcorrected. To free $C_s$ from this differential effect, the range from A0 to K0 must be increased by about 0.05 mag. Detailed corrections based on the effective wave lengths of the standard photographic and photovisual magnitudes are given in Table 9 of the following *Contribution*.[14] This table also gives the corrections required to reduce $C_s$ (which in Table 7 above is for the altitude of the pole) to the zenith and to zero air mass.

[12] Seares, Sitterly, and Joyner, *op. cit.*, n. 6. Since giants and dwarfs could not be differentiated, results for types later than G0 do not appear in Table 7.

[13] A. N. Vyssotsky, *Ap. J.*, **93**, 425, 1941.

[14] *Ap. J.*, **98**, 302, 1943.

TABLE 7

COLOR INDEX AND SPECTRAL TYPE

(Deviations, Unit 0.01 Mag., Are Followed by Numbers of Stars)

| HD Sp | Adopted $C_s$ | | Deviations, Observed *minus* Adopted $C_s$ | | | |
|---|---|---|---|---|---|---|
| | | | Wtd. Mean* | | Eros | Y |
| B3 | −0.44 | | −4 (1) | | | |
| 5 | −0.39 | | +2 (3) | | +5 (1) | |
| 7 | −0.33 | | 0 (7) | | | 0 (5) |
| 8 | −0.29 | | +1 (9) | | +3 (2) | 0 (5) |
| 8.5 | −0.26 | | +1 (8) | | | +2 (5) |
| 9 | −0.23 | | −1 (29) | | +4 (5) | +3 (7) |
| A0 | −0.15 | | +1 (96) | | +1 (21) | −1 (14) |
| 1 | −0.10 | | 0 (24) | | | −1 (7) |
| 2 | −0.05 | | 0 (90) | | −3 (13) | +5 (6) |
| 3 | −0.02 | | +1 (35) | | −1 (3) | −3 (3) |
| 5 | 0.00 | | 0 (61) | | −2 (9) | |
| 8 | +0.07 | | −1 (4) | | | |
| F0 | +0.12 | | 0 (103) | | −2 (26) | |
| 2 | +0.16 | | 0 (100) | | −5 (13) | |
| 3 | +0.19 | | 0 (5) | | | |
| 5 | +0.26 | | 0 (202) | | −3 (27) | |
| 6 | +0.29 | Giants | +2 (6) | Giants | | |
| 7 | +0.32 | | −1 (4) | | | |
| 8 | +0.35 | | 0 (242) | | −3 (33) | |
| 9 | +0.38 | | +2 (10) | | | |
| G0 | +0.42 | +0.60 | 0 (137) | − 2 (11) | −5 (27) | |
| 1 | +0.46 | +0.63 | +1 (8) | + 6 (3) | | |
| 2 | +0.50 | +0.67 | −3 (13) | 0 (3) | | |
| 3 | +0.55 | +0.71 | 0 (4) | − 3 (2) | | |
| 4 | +0.59 | +0.74 | +3 (5) | 0 (6) | | |
| 5 | +0.64 | +0.78 | 0 (69) | 0 (134) | | |
| 6 | +0.69 | +0.82 | +1 (2) | − 4 (5) | | |
| 7 | +0.74 | +0.86 | ..... | 0 (4) | | |
| 8 | +0.79 | +0.90 | 0 (40) | − 2 (67) | | |
| K0 | +0.89 | +1.06 | 0 (70) | 0 (111) | | |
| 1 | +0.95 | +1.14 | ..... | − 3 (2) | | |
| 2 | +1.01 | +1.25 | −1 (17) | 0 (58) | | |
| 3 | +1.06 | +1.37 | ..... | +12 (2) | | |
| 4 | ..... | +1.43 | ..... | + 4 (2) | | |
| 5 | ..... | +1.45 | ..... | 0 (16) | | |
| 6 | ..... | +1.46 | ..... | + 1 (1) | | |
| 8* | ..... | +1.47 | ..... | 0 (14) | | |
| 10 | ..... | +1.49 | ..... | 0 (5) | | |
| Total no. stars | | | 1404 | 446 | 180 | 52 |
| SD | | | +0.1 | +0.5 | −0.9 | +0.6 |
| AD | | | ±0.9 | ±2.1 | ±3.1 | ±1.9 |

* For giant stars Ma = K7.7, Mb = K9.7; for dwarfs, roughly, Ma = K6, Mb = K8.

TABLE 7—*Continued*

COLOR INDEX AND SPECTRAL TYPE

(Deviations, Unit 0.01 Mag., Are Followed by Numbers of Stars)

| HD Sp | Deviations, Observed *minus* Adopted $C_s$ | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | MW | | U | | Bg | | HD | |
| B3 | | | | | | | −4 (1) | |
| 5 | | | 0 (2) | | | | | |
| 7 | | | +1 (2) | | | | | |
| 8 | | | | | | | +1 (2) | |
| 8.5 | | | 0 (3) | | | | | |
| 9 | | | 0 (6) | | −11 (1) | | −5 (10) | |
| A0 | | | 0 (10) | | 0 (1) | | +1 (50) | |
| 1 | | | 0 (16) | | 0 (1) | | | |
| 2 | | | 0 (30) | | + 6 (3) | | 0 (38) | |
| 3 | | | +2 (5) | | − 1 (3) | | +2 (21) | |
| 5 | − 6 (2) | | 0 (27) | | − 7 (2) | | +1 (21) | |
| 8 | | | | | − 1 (4) | | | |
| F0 | + 5 (3) | | 0 (26) | | + 1 (3) | | 0 (45) | |
| 2 | + 2 (4) | | +1 (48) | | + 1 (10) | | +2 (25) | |
| 3 | 0 (1) | | | | 0 (4) | | | |
| 5 | 0 (1) | | +2 (134) | | − 3 (4) | | −3 (36) | |
| 6 | + 5 (2) | | | | 0 (4) | | | |
| 7 | − 1 (1) | | | | − 1 (3) | | | |
| 8 | − 2 (1) | | 0 (155) | | 0 (15) | | 0 (38) | |
| 9 | + 2 (1) | | | | + 2 (9) | | | |
| G0 | +10 (1) | + 3 (1) | +1 (75) | −5 (5) | 0 (16) | − 4 (1) | +5 (18)† | +2 (4) |
| 1 | | + 9 (1) | | | + 1 (8) | + 5 (2) | | |
| 2 | −10 (1) | | | | − 2 (12) | 0 (3) | | |
| 3 | + 3 (1) | | | | − 1 (3) | − 3 (2) | | |
| 4 | − 4 (2) | − 2 (3) | | | + 8 (3) | + 1 (3) | | |
| 5 | + 2 (1) | − 2 (1) | −1 (47) | 0 (62) | + 1 (3) | 0 (10) | +1 (18) | 0 (61) |
| 6 | | +11 (2) | | | + 1 (2) | −14 (3) | | |
| 7 | | − 5 (1) | | | | + 2 (3) | | |
| 8 | − 3 (1) | − 5 (3) | −1 (29) | −2 (57) | + 2 (10) | − 1 (7) | | |
| K0 | (−16) (1) | − 4 (2) | 0 (23) | −3 (50) | − 7 (1) | (−18) (1) | +1 (46) | +2 (59)‡ |
| 1 | | − 3 (2) | | | | | | |
| 2 | | + 1 (3) | −1 (10) | 0 (25) | − 2 (2) | + 2 (6) | +1 (5) | 0 (24) |
| 3 | | +12 (2) | | | (+17) (1) | | | |
| 4 | | + 1 (1) | | | | + 8 (1) | | |
| 5 | | +13 (3) | | | | − 8 (1) | | −2 (12) |
| 6 | | + 1 (1) | | | | | | |
| 8* | | + 9 (1) | | | | + 1 (1) | | −1 (12) |
| 10 | | 0 (3) | | | | | | 0 (2) |
| Total no. stars | 23 | 30 | 648 | 199 | 127 | 43 | 374 | 174 |
| SD | +0.2 | +2.4 | +0.2 | −2.0 | −0.5 | −0.8 | +0.2 | +0.1 |
| AD | ±3.7 | ±5.1 | ±0.6 | ±2.0 | ±2.4 | ±3.8 | ±1.8 | ±1.0 |

† HD dG0 The 9 stars having $m > 8.5$, $v = -0.15$, are omitted. See curve group 2, Fig. 2.

‡ HD gK0 Eleven stars, all but one having $m > 8.4$, $\rho > 400$, mean $v = \pm 0.17$, are omitted. The effect on $\bar{C}$ for HD is, however, only 0.01 mag.

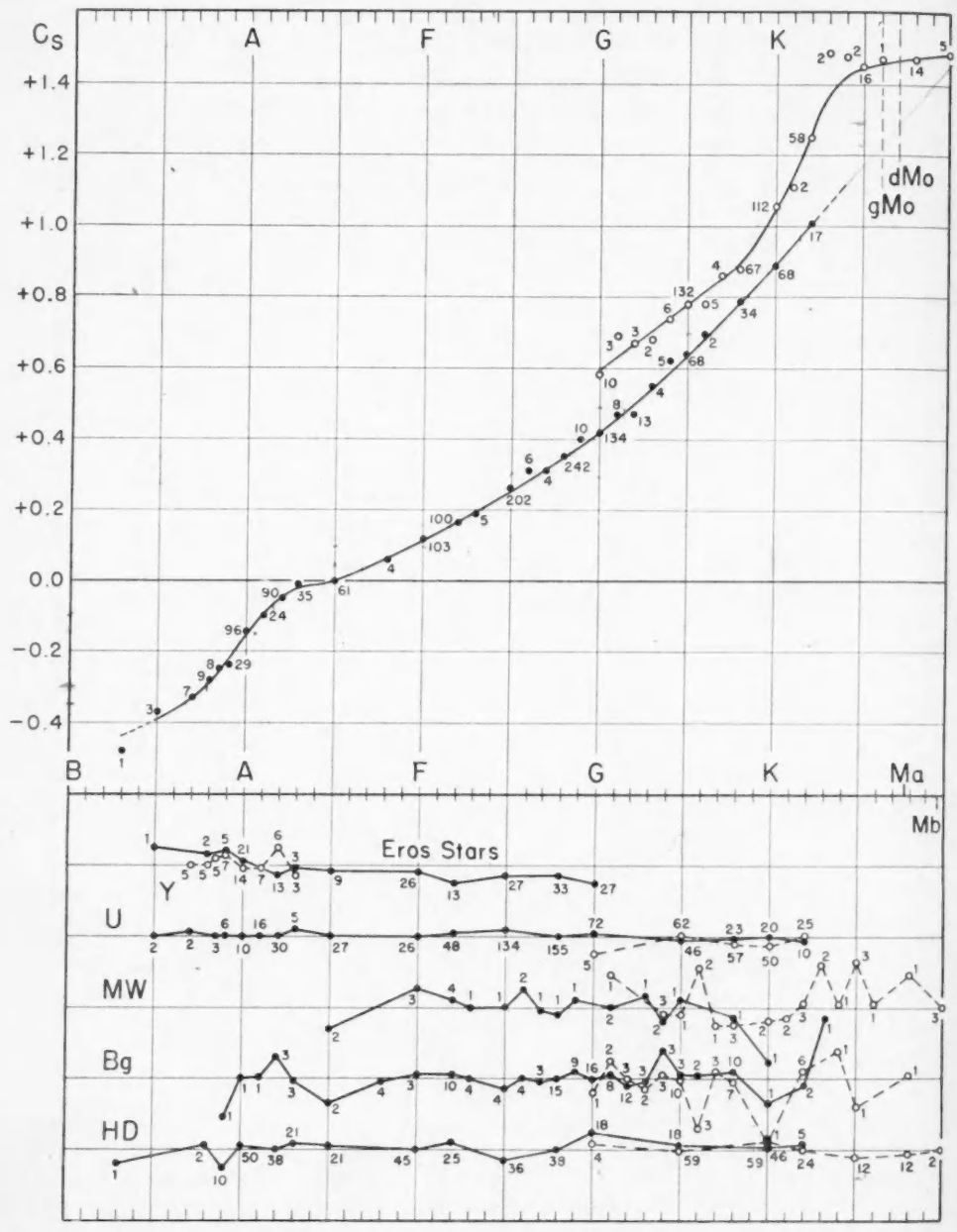



FIG. 4.—Color index and HD spectral type; *below*, deviations of the component spectral series from the mean curve (same scale of ordinates throughout). Figures indicate numbers of stars used. The values of $C_S$ have been freed from the mean color excess, i.e., for all types together, but still include the differential effect of stellar temperature on $E$; likewise, the similar differential effect on atmospheric extinction at the altitude of the Mount Wilson pole. See Table 9 of the following *Contribution*.

## VII. CALIBRATION OF U CLASSIFICATIONS FOR EARLY-TYPE STARS

Table 7 includes U data for 74 stars of types earlier than A5 which do not appear in Table 6. The original classifications (notation of Lindblad) could not be expressed in the usual notation until a reasonably good approximation for the spectrum-color relation had been found. The calibration process may now be explained.

The types and numbers of available spectra are shown in the first four columns of Table 8. For example, of the 10 A0$\kappa-$ stars for which $C$ is known, 4 occur in the HD and have the mean type A0.2. A progression in the HD types for the sequence of 10 U symbols is evident but not well determined; only half the stars are used, and the classification errors are disturbing. To avoid these difficulties, the calibration may be based on color equivalence, a procedure certainly unobjectionable for the present discussion. The $C$'s, however, must be corrected as usual.

TABLE 8

CALIBRATION OF UPSALA NOTATION FOR EARLY-TYPE STARS

| U | | HD | | PROVISIONAL | | ADOPTED | |
|---|---|---|---|---|---|---|---|
| Sp | No. | Sp | No. | $C$ | HD | $C$ | HD |
| A0$\sigma$ | 2 | B9 | 1 | −0.38 | B5 | −0.36 | B6 |
| A0$\sigma-$ | 2 | B9.5 | 2 | .32 | B7 | .32 | B7 |
| A0$\rho$ | 3 | B9 | 3 | .22 | B9.1 | .25 | B8.7 |
| A0$\mu$ | 6 | A0.7 | 6 | .20 | B9.4 | .20 | B9.4 |
| A0$\kappa-$ | 10 | A0.2 | 4 | .15 | A0 | .15 | A0 |
| A0$\kappa$ | 15* | A0 | 4 | .10 | A1 | .11 | A0.8 |
| A2$\mu$ | 1 | A3 | 1 | .12 | A0.6 | .09 | A1.2 |
| A2$\kappa-$ | 10 | A2.0 | 9 | .06 | A1.8 | .07 | A1.6 |
| A2$\kappa$ | 20 | A1.9 | 7 | − .04 | A2.3 | .04 | A2.3 |
| A3$\kappa$ | 5 | A6.0 | 2 | 0.00 | A5 | −0.02 | A3 |
| Total | 74 | ..... | 39 | ..... | ..... | ..... | ..... |

* BD 83°516, Pv 10.90; observed $C = +0.46$, has been rejected. The three Pg and six Pv magnitudes are all accordant. The reduced $C$ is 0.39 larger than the normal for the U type.

The distances of the HD stars found from $m$ and $M$ were compared with the distances $R$ given in the U catalogue. On the average, $\rho = 1.3R$. Rough distances on the scale used here could thus be found for U stars not in the HD, and hence also an approximate correction for the absorption. The resulting mean corrected $C$ for each U subtype appears in the fifth column of Table 8. The corresponding HD type found from values of $C_s$ based on the other data of Table 7 is in the sixth column. These inferred HD types are still provisional, since the distances used are uncertain, but sufficient to define the mean $M$ corresponding to the U types. A revision of the distances gives the adopted values of $C$ and of the equivalent HD type in the last two columns of Table 8. The progression in $C$ with the U type is generally smooth and the subtype intervals nearly constant.

As a check the data were completely reduced in the usual manner, with the inferred HD spectra as a starting-point. The absorption-curve thus found is normal. The magnitude corrections to $C$ for types A0$\sigma$–$\kappa$ agree with the lower curve of Figure 3, while those for A2$\mu$–$\kappa$ fit the upper curve better.

For insertion in Table 7 the results from Table 8 were slightly modified to eliminate the fractional subtypes. These additional data do not contribute anything to the form of the spectrum-color curve, but they should help to reduce the accidental errors in the mean colors for early-type stars.

## VIII. MEAN ABSORPTION FUNCTION

With the aid of $C_s$ in Table 7 and the adopted $\delta C$ of Figure 3 the individual values of the color excess $E$ can be revised and extended to include spectral series not used in the second approximation for the absorption function (Table 4). Combination of the results from all the useful data then gives the final approximation for $E = R_1(\rho)$, the mean relation for all types together.

The mean values of $E$ for stars within intervals of 50–100 parsecs for each of 17 spectral groups are collected in Table 9. These sequences of values are independent determinations of the absorption based on stars of different types as classified by different observers. The same material, regrouped as in Table 10, defines the adopted mean function, an average for the entire polar cap north of +80° declination. The Bg stars from the small field of Selected Area 1, however, are not included in the mean but are listed by themselves at the end of Table 10; further, the U B6–A3 stars are omitted from Table 10 altogether, since the magnitude correction to the colors of faint stars of these types is in doubt.

Certain details of the tables may now be noted. First, Table 9 begins with the results for 129 HD A stars, of which 12 (first line) have a mean distance of 80 parsecs and a mean $E$ of +0.048 mag., the latter 0.007 mag. greater (SD) than the value from the adopted curve of Table 10. The average deviation from this curve for the 12 stars is ±0.071 mag. Except for AD, the results for these 12 stars also appear in the third line of the third division of Table 10, alongside those for six similar values of the distance obtained from other spectral series listed in Table 9. The mean distance and the mean $E$ for these seven groups, weighted according to the numbers of stars (131 in all), given in the first and second columns at the end of the third division of Table 10 (boldface type), represent one of the 16 points which define the adopted mean absorption-curve. The weighted mean residual (fourth column) is insignificant and serves only as a check, except beyond 750 parsecs, where a constant mean $E = +0.28$ mag. has been used. These final results from Table 10, together with the means for the Bg stars in Selected Area 1, are collected in Table 11 and shown graphically in Figure 5.

The residuals (SD for groups of stars) in Table 9 indicate the agreement among the different spectral series and, through the values of AD, the average errors affecting individual stars. The general freedom of the results from systematic differences is partly a result of the reduction process. For example, it was necessary to assume that all the U gG and gK stars at a given distance were equally affected by absorption, that is, to disregard any effect arising from temperature differences in the stars. Again, the mean absorption for the giants between 350 and 550 parsecs was adjusted to equal that for main-sequence stars within the same interval. The adopted curve is therefore an average, corresponding to a temperature of, say, 7900° (F5).

The residuals of Table 10, on the other hand, show the accordance for stars at nearly the same distance, taken from different spectral series. For the intermediate distances, at least, these groups cover a wide range in apparent magnitude. As an illustration, for the seven groups having a mean distance of 173 parsecs, the values of $m$ corresponding to the mean $M$ for each group run as follows (rearranged in order of increasing $m$): 6.6, 7.0, 7.2, 7.2, 9.4, 9.4, 11.2. With allowance for the dispersion in $M$, it is clear that the whole interval in $m$ from 6 to 11 is well covered. The residuals, however, show a satisfactory alternation in sign and average only 0.01 mag. or less. It is hardly possible, therefore, that any serious systematic errors should remain undetected either in $C$ or in the spectral types.

For temperatures of 25,000° (B5) and 3500° (K2–5) the absorptions should be approximately 15 per cent larger and 18 per cent smaller, respectively, than the mean (see following *Contribution*), giving differences in $E$ of 0.04 or 0.05 mag. at most. For these extreme temperatures, however, the data are scanty; and any real systematic differences eliminated by the reduction process must be considerably less. At first sight, the U B6–

TABLE 9

ABSORPTION FUNCTION—$E$ FROM DIFFERENT SPECTRAL SERIES
(Unit 0.01 Mag.)

| $\rho$* | $E$ | No. | AD | SD |
|---|---|---|---|---|
| | HD A | | | |
| 80 | + 4.8 | 12 | ± 7.1 | + 0.7 |
| 124 | 5.2 | 20 | 6.7 | − 1.2 |
| 176 | 8.8 | 27 | 5.7 | − 0.2 |
| 224 | 10.9 | 31 | 5.5 | + 1.1 |
| 278 | 14.1 | 24 | 8.1 | + 1.6 |
| 342 | 14.3 | 10 | 9.9 | − 2.1 |
| 427 | +14.4 | 5 | ± 7.2 | − 6.2 |
| All | ..... | 129 | ± 6.8 | ..... |
| | HD F | | | |
| 41 | + 3.4 | 12 | ± 6.0 | + 1.2 |
| 66 | 4.6 | 33 | 4.7 | + 1.1 |
| 89 | 4.9 | 32 | 6.0 | + 0.4 |
| 123 | 5.4 | 46 | 6.0 | − 1.0 |
| 168 | 6.7 | 15 | 6.0 | − 2.0 |
| 206 | + 9.5 | 4 | ± 5.2 | + 0.2 |
| All | ..... | 142 | ± 5.7 | ..... |
| | HD dgG5† | | | |
| 38 | + 2.4 | 9 | ± 5.3 | + 0.4 |
| 63 | 3.0 | 11 | 8.8 | − 0.3 |
| 155 | 11.0 | 9 | 3.7 | + 3.0 |
| 219 | 7.9 | 14 | 7.8 | − 1.8 |
| 266 | 11.2 | 17 | 5.5 | − 0.6 |
| 324 | 17.5 | 11 | 7.9 | + 2.2 |
| 372 | 17.0 | 4 | 2.8 | − 0.9 |
| 447 | +25.0 | 4 | ± 3.2 | + 3.4 |
| All | ..... | 79 | ± 6.2 | ..... |
| | HD dgK0‡ | | | |
| 21 | + 1.4 | 15 | ± 3.6 | + 0.4 |
| 30 | − 0.9 | 16 | 7.1 | − 2.4 |
| 41 | + 2.6 | 15 | 6.3 | + 0.4 |
| 99 | + 8.0 | 8 | 11.0 | + 2.9 |
| 166 | + 7.5 | 6 | 15.8 | − 1.1 |
| 250 | +13.7 | 19 | 10.8 | + 2.6 |
| 341 | +17.7 | 18 | 11.9 | + 1.3 |
| 420 | +23.7 | 7 | ±17.1 | + 3.5 |
| All | ..... | 104 | ± 9.5 | ..... |

| $\rho$ | $E$ | No. | AD | SD |
|---|---|---|---|---|
| | Y B, A | | | |
| 80 | + 3.4 | 8 | ± 5.4 | − 0.7 |
| 134 | 7.4 | 8 | 3.2 | + 0.4 |
| 175 | 9.4 | 11 | 4.8 | + 0.4 |
| 233 | 11.2 | 10 | 5.5 | + 0.9 |
| 316 | 14.3 | 10 | 6.0 | − 0.7 |
| 406 | +19.4 | 5 | ± 4.0 | − 0.1 |
| All | ..... | 52 | ± 4.9 | ..... |
| | MW A–M§ | | | |
| 35 | + 2.4 | 10 | ± 7.7 | + 0.7 |
| 60 | 3.5 | 11 | 4.3 | + 0.3 |
| 84 | 2.8 | 10 | 7.0 | − 1.5 |
| 125 | 7.7 | 13 | 6.2 | + 1.2 |
| 222 | +10.4 | 10 | ±10.2 | + 0.6 |
| All | ..... | 54 | ± 7.0 | ..... |
| | U B6–A3‖ | | | |
| 67 | + 5.0 | 4 | ± 3.2 | + 1.5 |
| 145 | 5.0 | 13 | 5.2 | − 2.6 |
| 250 | 11.3 | 11 | 8.5 | + 0.2 |
| 333 | 14.6 | 14 | 7.3 | − 1.4 |
| 433 | 20.5 | 8 | 7.8 | − 0.5 |
| 536 | 28.7 | 6 | 9.5 | + 5.3 |
| 645 | 32.5 | 8 | 9.9 | + 6.2 |
| 741 | 30.5 | 4 | 7.0 | + 2.7 |
| 993 | +29.4 | 7 | ±14.3 | + 1.4 |
| All | ..... | 75 | ± 8.0 | ..... |
| | U A5 | | | |
| 59 | +14.0 | 1 | ±11 | +10.8 |
| 132 | 9.0 | 2 | 2.5 | + 2.1 |
| 215 | 11.4 | 5 | 7.8 | + 1.9 |
| 268 | 6.3 | 6 | 7.8 | − 5.6 |
| 382 | 20.1 | 6 | 7.7 | + 1.7 |
| 550 | 22.0 | 4 | 7.8 | − 1.7 |
| 670 | +28.0 | 2 | ±17.5 | + 1.2 |
| All | ..... | 26 | ± 8.2 | ..... |

| $\rho$ | $E$ | No. | AD | SD |
|---|---|---|---|---|
| | U F | | | |
| 52 | + 0.6 | 15 | ± 5.1 | − 2.2 |
| 82 | 2.3 | 19 | 7.7 | − 1.9 |
| 125 | 7.5 | 58 | 6.7 | + 1.0 |
| 175 | 9.5 | 67 | 6.5 | + 0.5 |
| 225 | 8.7 | 84 | 6.8 | − 1.1 |
| 275 | 11.8 | 70 | 9.1 | − 0.5 |
| 325 | 15.4 | 30 | 7.3 | 0.0 |
| 365 | 17.3 | 7 | 12.7 | − 0.2 |
| 430 | +25.3 | 6 | ± 7.3 | + 4.4 |
| All | ..... | 356 | ± 7.3 | ..... |
| | U dG, K | | | |
| 35 | + 2.3 | 38 | ± 5.8 | + 0.6 |
| 75 | 4.9 | 42 | 6.2 | + 0.9 |
| 125 | 6.1 | 41 | 7.0 | − 0.4 |
| 175 | 8.9 | 35 | 6.5 | − 0.1 |
| 218 | +11.8 | 20 | ± 6.5 | + 2.1 |
| All | ..... | 176 | ± 6.4 | ..... |
| | U gG5 | | | |
| 52 | − 3.0 | 1 | ± 6 | − 6 |
| 216 | + 9.0 | 6 | 4.5 | − 0.7 |
| 332 | +14.8 | 6 | 4.8 | − 1.2 |
| 414 | +18.3 | 6 | 7.0 | − 1.7 |
| 537 | +22.0 | 7 | 7.4 | − 1.4 |
| 642 | +27.7 | 9 | 7.6 | + 1.5 |
| 759 | +23.0 | 10 | 9.6 | − 5.0 |
| 874 | +28.8 | 6 | 8.2 | + 0.8 |
| 949 | +26.2 | 10 | 7.6 | − 1.8 |
| 1056 | +25 : | 3 | ± 3.3 | − 3 |
| All | ..... | 64 | ± 7.1 | ..... |
| | U gG8 | | | |
| 273 | +12.2 | 4 | ± 3.0 | − 0.1 |
| 367 | 14.1 | 7 | 7.0 | − 3.6 |
| 443 | 23.1 | 10 | 7.1 | + 1.6 |
| 581 | 22.7 | 9 | 9.0 | − 1.9 |
| 665 | 26.0 | 8 | 9.4 | − 0.7 |
| 758 | 30.5 | 13 | 9.0 | + 2.5 |
| 865 | 22.6 | 5 | 5.4 | − 5.4 |
| 981 | +24.5 | 13 | ± 4.4 | − 3.5 |
| All | ..... | 69 | ± 7.1 | ..... |

* Distances, in parsecs, have not been corrected for absorption.
† First group, all dwarfs; second, dwarfs and two giants; other groups, giants.
‡ First three groups, dwarfs; others, giants.
§ Thirty giants, 34 main sequence.
‖ Not included in Table 10.

TABLE 9—*Continued*

| ρ | E | No. | AD | SD |
|---|---|---|---|---|
| | U gK0 | | | |
| 466 | +26.0 | 4 | ±10.0 | + 4.0 |
| 545 | 27.5 | 4 | 10.5 | + 3.8 |
| 639 | 20.9 | 11 | 12.4 | − 5.3 |
| 727 | 30.7 | 6 | 6.7 | + 3.2 |
| 859 | 25.1 | 7 | 6.9 | − 2.9 |
| 924 | 29.1 | 7 | 6.9 | + 1.1 |
| 1080 | +25.7 | 3 | ±11.7 | − 2.3 |
| All | ..... | 42 | ± 9.3 | ..... |
| | U gK2, 5 | | | |
| 435 | +17.8 | 9 | ±11.7 | − 3.4 |
| 554 | 26.2 | 8 | 10.5 | + 2.4 |
| 656 | 35.6 | 5 | 14.6 | + 9.1 |
| 941 | +30.5 | 10 | ± 5.7 | + 2.5 |
| All | ..... | 32 | ±10.0 | ..... |

| ρ | E | No. | AD | SD |
|---|---|---|---|---|
| | Bg A, F | | | |
| 76 | + 5.5 | 2 | ± 4.5 | + 1.5 |
| 123 | 8.2 | 12 | 3.2 | + 1.8 |
| 176 | 9.3 | 13 | 4.3 | + 0.3 |
| 224 | 9.5 | 20 | 5.8 | − 0.3 |
| 307 | 13.7 | 9 | 5.8 | − 0.6 |
| 429 | 23.3 | 6 | 9.2 | + 2.6 |
| 575 | +23.6 | 5 | ± 6.0 | − 0.8 |
| All | ..... | 67 | ± 5.3 | ..... |
| | Bg dgG¶ | | | |
| 53 | − 1.9 | 7 | ± 8.4 | − 4.9 |
| 119 | +11.4 | 12 | 9.0 | + 5.3 |
| 172 | + 7.1 | 16 | 8.4 | − 1.9 |
| 209 | +10.5 | 17 | 7.8 | + 1.1 |
| 315 | +11.2 | 8 | 7.4 | − 3.7 |
| 519 | +25.6 | 7 | 10.7 | + 2.4 |
| 697 | +28.1 | 9 | 9.7 | + 1.1 |
| 816 | +34.2 | 6 | 11.5 | + 6.2 |
| 916 | +18.0 | 6 | 10.0 | −10.0 |
| 1246 | +22.0 | 3 | ± 8.7 | − 6.0 |
| All | ..... | 91 | ± 8.9 | ..... |

| ρ | E | No. | AD | SD |
|---|---|---|---|---|
| | Bg dgK** | | | |
| 71 | +11.0 | 3 | ±10.7 | + 7.2 |
| 206 | 8.5 | 2 | 9.0 | − 0.8 |
| 590 | 28.2 | 4 | 10.0 | + 3.5 |
| 914 | +26.0 | 4 | ±14.0 | − 2.0 |
| All | ..... | 13 | ±11.2 | ..... |

¶ First four groups, dwarfs and one giant; fifth group, six dwarfs, two giants; others, giants.

** First group, dwarfs; others, giants.

## NOTES TO TABLE 9

In addition to the stars rejected in preparing Table 5, a number of others, listed below, have been omitted from Tables 9 and 10, usually when $v > +0.25$ mag., but sometimes only because the star was judged to be too faint for reliable classification.

HD A Because of its distance, one A0 star has been included with the first group of F's.

HD F BD 80°4, 80°258, 84°216, $v = -0.25$, $-0.21$, $-0.09$, respectively, omitted. All are too faint for reliable HD classification.

HD dG0 The 27 stars, all within 100 parsecs, are not used. The residual curve, group 4, Fig. 2, suggests magnitude error in $C$—not confirmed, however, by the other data. Classification errors seem to be present.

HD gK0 The 13 stars shown in the accompanying tabulation have been omitted. In the absence of other data, BD 81°710 should have been used as a dwarf for Table 5 ($v = +0.09$).

| BD | Pv | v | BD | Pv | v |
|---|---|---|---|---|---|
| 80°302 | 8.81 | −0.16 | 84° 59 | 5.61 | −0.29 MW gG4 |
| 451 | 7.30 | + .50 | 217 | 8.73 | − .16 |
| 468 | 8.52 | + .31 | 225 | 6.33 | + .36 |
| 657 | 6.62 | − .25 MW gG9 | 85 3 | 8.52 | + .38 |
| 81 710 | 8.23 | − .24 | 87 79 | 8.32 | − .25 U, Bg gG8 |
| 82 82 | 7.28 | + .27 | 80 | 8.66 | −0.19 U G8 |
| 280 | 8.65 | −0.13 | | | |

HD gK2, 5 The mean $v$ for 24 gK2 stars is ±0.15 mag., a value not abnormal, since near gK2 the change in $C$ is 0.11 mag. per classification unit. The mean $E$ is correct in amount, but the increase with distance is not well defined. The stars are not used. The 12 gK5 stars are much more accordant ($v = \pm 0.09$ mag.), as is to be expected, but the series is too short to be useful.

U A, F The following stars have been omitted:

| BD | Pv | Sp | $v$ | BD | Pv | Sp | $v$ |
|---|---|---|---|---|---|---|---|
| 82°520 | 10.67 | F2 | +0.26 | 86°132 | 9.04 | F8 | +0.31 |
| 83 510 | 9.19 | F8 | .28 | 301 | 10.67 | F8 | .33 |
| 85 387 | 10.48 | A5 | .26 | 322 | 10.77 | F2 | .27 |
| 397 | 10.76 | F0 | +0.31 | 87 87 | 10.57 | F8 | +0.36 |

Aside from these 8 residuals there are none $>+0.23$ and no value $<-0.24$. Within these limits the 382 residuals are normal in distribution and have a mean value of $\pm 0.074$ mag. The ME of the observed $C$ for the first star, the least reliable of the 8, is $\pm 0.05$ mag. The stars are not exceptionally faint in comparison with those having normal residuals, and errors of a whole spectral class, which would be required to account for the discordances, are scarcely admissible. The suggestion is rather in the direction of unusual values of $E$, that is, departures from the mean absorption-curve.

U dG, K Eight stars, shown in accompanying tabulation, all but one close to the classification limit, were not used. The last, dG0, Pv 8.48, is HD F0. The others account for 0.03 of the 0.05-mag. divergence in the last point of the residual curve (Table 5).

| BD | $v$ | BD | $v$ | BD | $v$ | BD | $v$ |
|---|---|---|---|---|---|---|---|
| 82° 9 | −0.23 | 84°259 | −0.30 | 85°109 | −0.26 | 85°301 | −0.32 |
| 83 643 | −0.23 | 85 58 | −0.22 | 85 212 | −0.24 | 85 412 | −0.21 |

U gG5 BD 86°262, $v = +0.27$, omitted.

U gG8 BD 81°789 and 85°183, $v = -0.16, -0.13$, used as giants for Table 5, were reclassified as dwarfs ($v = +0.05$ for both), and so used for Tables 9 and 10.
BD 85°207, 85°381, 85°395, and 86°59; $v = +0.37, +0.37, +0.25$, and $+0.27$, respectively, were omitted. Either $E$ for these stars is abnormally large or the types should be K0–2.

U gK0 The following stars were originally used as giants for Table 5:

| | | | | |
|---|---|---|---|---|
| BD 82°546 | 82°728 | 86°174 | 82°162 | 86°117 |
| | 86 166 | 87 104 | 85 7 | 87 166 |

If the giant designations are correct, the types for all 9 stars should probably be K2. If type K0 is accepted, the first 5 become dwarfs and the last 4 borderline cases. For uniformity with the procedure followed elsewhere the latter alternative is adopted, although the residuals for the dwarfs remain definitely systematic with a mean of +0.10 mag. The stars are included in the list on p. 270 but have not been used at all for Tables 9 and 10.

U gK2, 5 BD 82°126, $v = -0.25$, omitted; since, as a dwarf, $v$ would be +0.22, the star is a borderline case and is now listed as such in the notes to Table 5. Also omitted, 9 stars, Pv $\leqslant$ 7.70; curve group 8, Fig. 2, shows that either the colors or the spectra of these stars are abnormal. Since the HD curves for the same types (groups 9, 10) are normal, the U spectra are under suspicion. In effect, therefore, only stars between $m = 8.0$ and 10.0, for which $C$ is certainly free from magnitude and classification errors, have been retained for Tables 9 and 10.

Bg dK2 BD 89°16, $v = -0.14$, omitted because $C$ depends on a single Pg $m$.

A3 stars (Table 9), which were reduced independently of the other data, seem to give a definite departure in the right direction; beyond 500 parsecs all the values of $E$ are larger than the average by about the right amount. But here, as already remarked, there is uncertainty as to the magnitude correction required by the color indices. If the correction is zero for faint B and A stars, as it is for other types, the large residuals would disappear.

The distances used thus far are everywhere the apparent values calculated from $M$, the mean photovisual absolute magnitude for the type in question, and $m$, the observed apparent magnitude, which includes the total photovisual absorption $A_{pv}$. The corrected distance $\rho_c$ may be found from

$$\log \rho_c = \log \rho - 0.2 A_{pv}, \qquad A_{pv} = R_{pv} E. \tag{5}$$

TABLE 10

ADOPTED ABSORPTION FUNCTION FROM STARS NORTH OF +80°

| $\rho$ | $v, E$ | No. | Series |
|---|---|---|---|
| 21.. | + 0.4 | 15 | HD, K0 |
| 30.. | − 2.4 | 16 | HD, K0 |
| 35.. | + 0.7 | 10 | MW |
| 35.. | + 0.6 | 38 | U, GK |
| 38.. | + 0.4 | 9 | HD, G5 |
| 41.. | + 1.2 | 12 | HD, F |
| 41.. | + 0.4 | 15 | HD, K0 |
| **34..** | **+ 1.9*** | **115** | **+0.3** |
| 52.. | − 6 | 1 | U, G5 |
| 52.. | − 2.2 | 15 | U, F |
| 59.. | +11 | 1 | U, A5 |
| 60.. | + 0.3 | 11 | MW |
| 63.. | − 0.3 | 11 | HD, G5 |
| 66.. | + 1.1 | 33 | HD, F |
| **62..** | **+ 3.4** | **72** | **+0.1** |
| 75.. | + 0.9 | 42 | U, GK |
| 80.. | − 0.7 | 8 | Y, BA |
| 80.. | + 0.7 | 12 | HD, A |
| 82.. | − 1.9 | 19 | U, F |
| 84.. | − 1.5 | 10 | MW |
| 89.. | + 0.4 | 32 | HD, F |
| 99.. | + 2.9 | 8 | HD, K0 |
| **82..** | **+ 4.4** | **131** | **+0.2** |
| 123.. | − 1.0 | 46 | HD, F |
| 124.. | − 1.2 | 20 | HD, A |
| 125.. | + 1.2 | 13 | MW |
| 125.. | + 1.0 | 58 | U, F |
| 125.. | − 0.4 | 41 | U, GK |
| 132.. | + 2.1 | 2 | U, A5 |
| 134.. | + 0.4 | 8 | Y, BA |
| **125..** | **+ 6.5** | **188** | **0.0** |
| 155.. | + 3.0 | 9 | HD, G5 |
| 166.. | − 1.1 | 6 | HD, K0 |
| 168.. | − 2.0 | 15 | HD, F |
| 175.. | + 0.4 | 11 | Y, BA |
| 175.. | + 0.5 | 67 | U, F |
| 175.. | − 0.1 | 35 | U, GK |
| 176.. | − 0.2 | 27 | HD, A |
| **173..** | **+ 9.0** | **170** | **+0.1** |
| 206.. | + 0.2 | 4 | HD, F |
| 215.. | + 1.9 | 5 | U, A5 |
| 216.. | − 0.7 | 6 | U, G5 |
| 218.. | + 2.1 | 20 | U, GK |
| 219.. | − 1.8 | 14 | HD, G5 |
| 222.. | + 0.6 | 10 | MW |
| 224.. | + 1.1 | 31 | HD, A |
| 225.. | − 1.1 | 84 | U, F |
| 233.. | + 0.9 | 10 | Y, BA |
| **223..** | **+ 9.7** | **184** | **−0.1** |
| 250.. | + 2.6 | 19 | HD, K0 |
| 266.. | − 0.6 | 17 | HD, G5 |
| 268.. | − 5.6 | 6 | U, A5 |
| 273.. | − 0.1 | 4 | U, G8 |
| 275.. | − 0.5 | 70 | U, F |
| 278.. | + 1.6 | 24 | HD, A |
| **271..** | **+12.2** | **140** | **+0.1** |
| 316.. | − 0.7 | 10 | Y, BA |
| 324.. | + 2.2 | 11 | HD, G5 |
| 325.. | 0.0 | 30 | U, F |
| 332.. | − 1.2 | 6 | U, G5 |
| 341.. | + 1.3 | 18 | HD, K0 |
| 342.. | − 2.1 | 10 | HD, A |
| **329..** | **+15.9** | **85** | **+0.1** |
| 365.. | − 0.2 | 7 | U, F |
| 367.. | − 3.6 | 7 | U, G8 |
| 372.. | − 0.9 | 4 | HD, G5 |
| 382.. | + 1.7 | 6 | U, A5 |
| 406.. | − 0.1 | 5 | Y, BA |
| 414.. | − 1.7 | 6 | U, G5 |
| 420.. | + 3.5 | 7 | HD, K0 |
| **390..** | **+18.6** | **42** | **−0.1** |
| 427.. | − 6.2 | 5 | HD, A |
| 430.. | + 4.4 | 6 | U, F |
| 435.. | − 3.4 | 9 | U, K2, 5 |
| 443.. | + 1.6 | 10 | U, G8 |
| 447.. | + 3.4 | 4 | HD, G5 |
| 466.. | + 4.0 | 4 | U, K0 |
| **440..** | **+21.4** | **38** | **+0.3** |
| 537.. | − 1.4 | 7 | U, G5 |
| 545.. | + 3.8 | 4 | U, K0 |
| 550.. | − 1.7 | 4 | U, A5 |
| 554.. | + 2.4 | 8 | U, K2, 5 |
| 581.. | − 1.9 | 9 | U, G8 |
| **556..** | **+23.9** | **32** | **0.0** |
| 639.. | − 5.3 | 11 | U, K0 |
| 642.. | + 1.5 | 9 | U, G5 |
| 656.. | + 9.1 | 5 | U, K2, 5 |
| 665.. | − 0.7 | 8 | U, G8 |
| 670.. | + 1.2 | 2 | U, A5 |
| **647..** | **+26.3** | **35** | **−0.1** |
| 727.. | + 3.2 | 6 | U, K0 |
| 758.. | + 2.5 | 13 | U, G8 |
| 759.. | − 5.0 | 10 | U, G5 |
| **752..** | **+28.0** | **29** | **+0.1** |
| 859.. | − 2.9 | 7 | U, K0 |
| 865.. | − 5.4 | 5 | U, G8 |
| 874.. | + 0.8 | 6 | U, G5 |
| **869..** | **+25.7** | **18** | **−2.4** |
| 924.. | + 1.1 | 7 | U, K0 |
| 941.. | + 2.5 | 10 | U, K2, 5 |
| 949.. | − 1.8 | 10 | U, G5 |
| **944..** | **+28.6** | **27** | **+0.5** |
| 981.. | − 3.5 | 13 | U, G8 |
| 1056.. | − 3: | 3 | U, G5 |
| 1080.. | − 2.3 | 3 | U, K0 |
| **1009..** | **+24.7** | **19** | **−3.2** |
| | Bg† | | |
| 53.. | − 4.9 | 7 | G |
| 71.. | + 7.2 | 3 | K |
| 76.. | + 1.5 | 2 | AF |
| **61..** | **+ 2.6*** | **12** | **−0.8** |
| 119.. | + 5.3 | 12 | G |
| 123.. | + 1.8 | 12 | AF |
| **121..** | **+ 9.8** | **24** | **+3.6** |

* Mean $E$ corresponding to the distance (uncorrected for absorption) in the column preceding. These means define the adopted absorption function. The residuals $v$ standing above each $E$ are the deviations in $E$ for the constituent spectral series. Unit for $E$ and $v$, 0.01 mag.

† Not included with the other data, since the field covered (Selected Area 1) is only 3.5° square.

TABLE 10—*Continued*

| $\rho$ | $v, E$ | No. | Series | $\rho$ | $v, E$ | No. | Series | $\rho$ | $v, E$ | No. | Series |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Bg† | | | | Bg† | | | | Bg† | | |
| 172.. | − 1.9 | 16 | G | 307.. | − 0.6 | 9 | AF | 697.. | + 1.1 | 9 | G |
| 176.. | + 0.3 | 13 | AF | 315.. | − 3.7 | 8 | G | 816.. | + 6.2 | 6 | G |
| | | | | 429.. | + 2.6 | 6 | AF | 914.. | − 2.0 | 4 | K |
| | | | | | | | | 916.. | −10.0 | 6 | G |
| **174..** | **+ 8.1** | **29** | **−0.9** | **341..** | **+15.3** | **23** | **−0.8** | | | | |
| | | | | | | | | **813..** | **+26.8** | **25** | **−0.8** |
| 206.. | − 0.8 | 2 | K | 519.. | + 2.4 | 7 | G | | | | |
| 209.. | + 1.1 | 17 | G | 575.. | − 0.8 | 5 | AF | 1246.. | +22.0 | 3 | G |
| 224.. | − 0.3 | 20 | AF | 590.. | + 3.5 | 4 | K | | | | |
| **217..** | **+ 9.9** | **39** | **+0.3** | **554..** | **+25.6** | **16** | **+1.7** | | | | |

TABLE 11

ABSORPTION FUNCTION $E = R_1(\rho)$

| Appt. $\rho$ | Corrected $\rho$ | $E$ | No. Values | Appt. $\rho$ | Corrected $\rho$ | $E$ | No. Values |
|---|---|---|---|---|---|---|---|
| | | | | Bergedorf (Bg) | | | |
| 34..... | 33 | 1.9 | 115 | | | | |
| 62..... | 58 | 3.4 | 72 | | | | |
| 82..... | 76 | 4.4 | 131 | | | | |
| 125..... | 112 | 6.5 | 188 | | | | |
| 173..... | 148 | 9.0 | 170 | 61..... | 58 | 2.6 | 12 |
| 223..... | 188 | 9.7 | 184 | 121..... | 102 | 9.8 | 24 |
| 271..... | 219 | 12.2 | 140 | 174..... | 151 | 8.1 | 29 |
| 329..... | 249 | 15.9 | 85 | 217..... | 182 | 9.9 | 39 |
| 390..... | 282 | 18.6 | 42 | 341..... | 261 | 15.3 | 23 |
| 440..... | 302 | 21.4 | 38 | 554..... | 354 | 25.6 | 16 |
| 556..... | 366 | 23.9 | 32 | 813..... | 507 | 26.8 | 25 |
| 647..... | 408 | 26.3 | 35 | 1246..... | 778 | 22.0 | 3 |
| 752..... | 469 | 28.0 | 29 | | | | |
| 869..... | 542 | 25.7 | 18 | | | | |
| 944..... | 589 | 28.6 | 27 | | | | |
| 1009..... | 630 | 24.7 | 19 | | | | |

The factor $R_{pv}$, which varies slowly with stellar temperature, is calculated in the following *Contribution* (Table 7) on the assumption that the absorption varies as $\lambda^{-1}$. The value used here is 3.77, corresponding to $T = 7900°$ (F5). The formula for corrected distance thus becomes

$$\log \rho_c = \log \rho - 0.75E . \qquad (6)$$

The results for $\rho_c$ are given in the second column of Table 11. The curve for $E$ as a function of corrected distance, also shown in Figure 5, indicates a nearly linear increase to 400 parsecs and, from about 450 parsecs on, suggests a constant ordinate of 0.27 mag., 0.01 less than the value from the second approximation.

In spite of the relatively low weight of the outlying points, it seems probable that the cloud ends at about 450 parsecs. The corresponding total absorptions would be $A_{pv} = 3.77 \times 0.27 = 1.0$ mag., $A_{pg} = 4.77 \times 0.27 = 1.3$ mag. (mean type F5, $T$ 7900°). In any case, the behavior of the 100 stars beyond 500 parsecs corrected distance, including

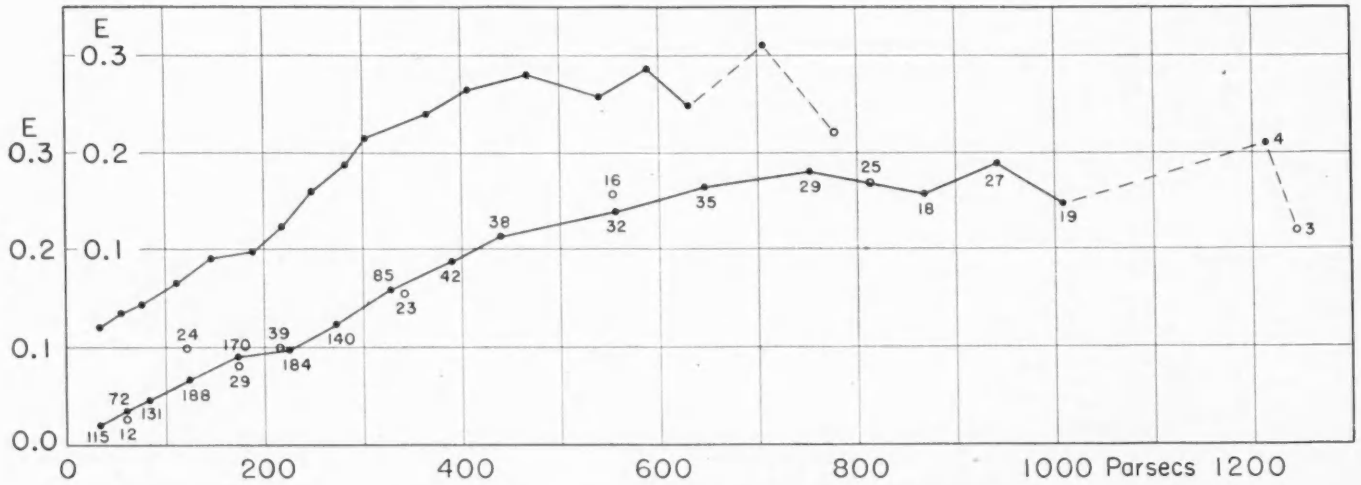



FIG. 5.—Absorption relation for stars north of +80° declination. Mean color excess (all types together) and distance; *below*, distance uncorrected for absorption; *above*, corrected distance. Figures indicate numbers of stars; circles (*lower curve*), stars in Selected Area 1, not included in the mean curve. The last point but one corresponds to 4 distant M-type stars not given in the tabular data. For a $\lambda^{-1}$ law the Pg and Pv absorptions are, respectively, 4.77 and 3.77 times the values of $E$. The flattening of the curve suggests that the obscuring cloud ends at about 400 parsecs (corrected distance).

the 4 distant U M's which do not appear in Tables 9–11,[15] is inconsistent with a continued increase in the absorption at anything like the initial rate, and it is unlikely that any type of systematic error or selection can account for the divergence. Near the limiting magnitude, selection would favor the more luminous stars of any given type and for a continually increasing absorption would tend actually to raise the extremity of the curve. The distances assigned to such stars, having been calculated with the mean $M$ for the type instead of their true luminosities, would be too small, and the values of $E$ associated with them relatively too large.

It should also be noted that the slope of the approximately linear portion of the curve is slightly too steep because of a statistical error for which no exact allowance can be made. Owing to the dispersion in $M$ for stars of a given type, the distance calculated from the mean $M$ will be less than the mean of the distances corresponding to the individual $M$'s. The effect on the curve is thus similar to that produced by selection near the limiting magnitude.

Finally, since the maximum deviations in the linear region are only 0.02 mag., the obscuring cloud must be of rather uniform structure—a conclusion supported by the Bg results from the $3.5° \times 3.5°$ field of Selected Area 1. The influence of the cloud is already appreciable at a distance of about 30 parsecs, and the smoothness of the curve for the first 150 parsecs (676 values of $E$) suggests that the solar system may lie within the cloud.

*Comparison with photoelectric observations.*—These results have been compared with the values of $E$ found from the photoelectric measurements of Stebbins, Huffer, and Whitford[5] reduced to the scales of distance and color used here. By plotting the observed colors $C_1$ for each subtype against the apparent distance, we obtain, with sufficient accuracy for reducing $C_1$ to zero distance, the provisional relation $E_1 = 0.00019\rho$. Combination of the reduced values according to type then gives the color-spectrum relation $C_{1s}$, whence, for each star, $E_1 = C_1 - C_{1s}$. Grouping $E_1$ according to distance and multiplying the mean values by 2.12,[16] we find the values given in the accompanying tabulation. Here the third line indicates the deviations (unit, 0.01 mag.) from the corresponding values of $E$ obtained from the data of Table 11.

| | | | | | | |
|---|---|---|---|---|---|---|
| Appt. $\rho$ | 111 | 204 | 305 | 392 | 486 | 700 |
| $2.12\,E_1$ | 5.5 | 9.1 | 12.9 | 13.1 | 19.9 | (15.9) |
| $2.12\,E_1 - E$ | −0.2 | −0.2 | −1.1 | −5.5 | −2.6 | (−11.1) |
| No. stars | 16 | 23 | 16 | 9 | 5 | 2 |

[15] M-type stars were not included in the solution for absorption because of their small number and the large scatter in their colors. Two other groups not shown in Fig. 5 agree satisfactorily with the curve: $\rho = 224$, 545 parsecs (apparent); $E = 7.4$, 25.3, respectively. The colors for 7 additional M stars are peculiar (see sec. xii).

[16] The theoretical conversion factor for reducing $E_1$ for A0 stars to the scale of $E$, from Table 7 of the following *Contribution*. For an absorption varying as $\lambda^{-1}$ the factor should be the same as the coefficient in equation (4) above.

*Note added October 12, 1943*—The recent article by Stebbins and Whitford (*Mt. W. Contr.*, No. 680; *Ap. J.*, **98**, 20, 1943) throws additional light on the comparison given here. The departures from the $\lambda^{-1}$ law shown by the data in their Table 9, together with the effective wave lengths of the $C$ and $C_1$ systems from Table 3 ($T = 17{,}000°$) of the following *Contribution*, No. 685, lead to the ratio $E/E_1 = 2.4$. The differences (unit, 0.01 mag.)

$$2.4E_1 - E = +0.5,\ +0.9,\ +0.4,\ -3.9,\ -0.2,\ (-9.2)\,,$$

should therefore replace the sequence given in the text. The agreement is perhaps best expressed by the rate of increase in $E$, which to 500 parsecs apparent distance is sensibly linear. The photoelectric measurements give 0.48, those discussed here, 0.46 mag/kpsc. As noted in the text, the former, theoretically, should exceed the latter by about 10 per cent. Since the use of $C/C_1 = 1.90$ (eq. [4*a*], n. 11) for $E/E_1$ would have given 0.38 instead of 0.48 mag/kpsc, the two series of measurements are consistent with the departures from the $\lambda^{-1}$ law observed by Stebbins and Whitford.

The value of $E_1$ for 392 parsecs is obviously low; had a smoothed curve for $E_1$ been used, the deviation from $E$ would have been $-2.3$ instead of $-5.5$. One of the stars at 700 parsecs gives a difference of $-6$, which for a single star is normal. The other is almost certainly an instance of abnormal color. Both $C$ and $C_1$ are low for the type assigned, and the type itself cannot be seriously in error. The systematic divergence beginning at 300 parsecs would be increased by about 10 per cent of $E$ if allowance were made for the theoretical effect of temperature difference in the stars used to find $E_1$ and $E$. But just in this region the uncertainties inherent in small groups of stars become increasingly important. It is not a question of the accuracy of the $C_1$ colors but of the much larger influence of perfectly normal classification errors and of individual deviations from the mean absorption.

The flattening-out of the curve for $E$ beyond 500 parsecs at least is not contradicted by the two values of $E_1$ for 700 parsecs. An uninterrupted increase would require for this distance $E_1 = 0.14$ mag. and leave for these stars residuals of $-0.04$ and $-0.09$ mag. ($E_1$ scale), both negative and the latter improbable, since for the remaining 69 stars only three residuals exceed 0.05 mag.

## IX. DEVIATIONS FROM THE MEAN ABSORPTION-CURVE

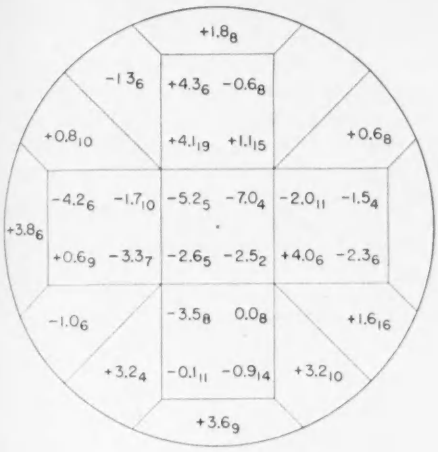
The general uniformity of the obscuring cloud suggested by the results shown in Table 11 and Figure 5 may be examined further with the aid of Figure 6, which gives results for stars at different distances in 32 small fields around the pole. The boundaries of these fields were fixed by quartering the four areas covered by the Upsala spectra (each $6° \times 6°$, centered at $+85°$ declination) and the square area included between them and then subdividing further as indicated by the diagrams.

The figures within the diagrams show for each small field the algebraic mean residual $SD_n$ (unit 0.01 mag.), and $n$, the number of stars included. Below are given, in succession, the distance interval (apparent); the total number of stars, $N$; the mean $SD_N$ for all the $N$ stars; the value of $SD'_N$, the unweighted algebraic mean of the $SD_n$'s for the 32 (sometimes fewer) fields; the mean AD per star ($\bar{v}$) based on the $N$ stars within the interval; and, finally, the arithmetic mean of $SD_n$ ($\bar{v}_n$). Since the corners of the Upsala areas overlap slightly, 28 stars are counted twice. Further, 160 of the 1496 values of $v$ included in Table 10 represent duplicate observations of spectra. The mean residual for duplicate observations has been treated as a single value. These slight inconsistencies in weighting are of no consequence.

The small values for $SD_N$ and $SD'_N$ (the latter merely disregards differences in $n$) show that the positive and negative residuals balance, as they should for any considerable number of stars, on the supposition that the adopted $C_s$ and $E$ functions are really the averages defined by the data. The values of $SD_n$, on the other hand, are appreciable and show a clustering of algebraic signs, which suggests the influence of local systematic irregularities. These irregularities are now to be examined, especially in respect to the uniformity of the absorption.

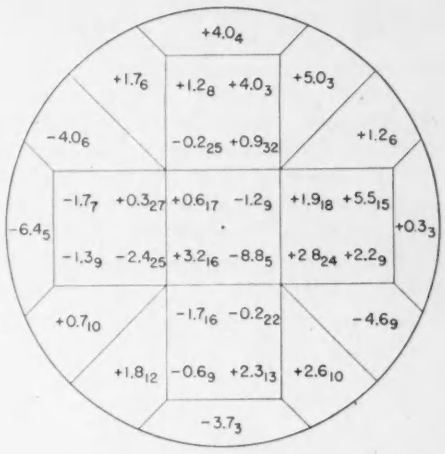
Besides deviations from the mean absorption, $SD_n$ includes, first, the sampling error arising from the small values of $n$ and the relatively large accidental component in the residuals—a composite of observation errors in spectrum and color and of dispersion in the colors of stars of the same subtype; and, second, possibly at least, a zero-point error in $C$, varying slowly over the polar cap. For a small field such an error would operate systematically and combine with the integrated effect of deviations from the mean absorption.

The matter is clarified somewhat by Figure 7, similar to the diagrams of Figure 6 but giving values of $SD_n$ for stars at all distances. The influence of sampling error has been reduced by about one-half, and any local irregularities in absorption in the line of sight must also have been smoothed out to a considerable extent. Figure 7 therefore emphasizes the combined effect of zero-point error and of variations across the polar cap in the



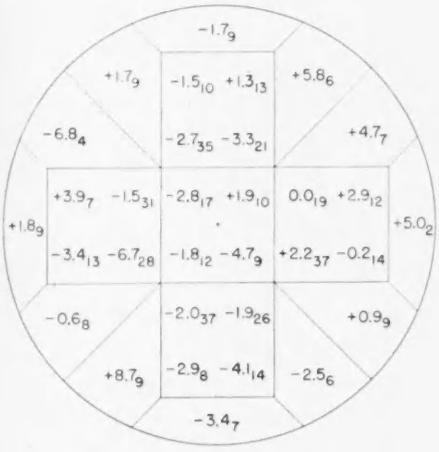

$\rho < 100$, $SD_N$ +0.2, $\bar{v}$ ±5.7

N 247, $SD'_N$ -0.2, $\bar{v}_n$ ±2.4



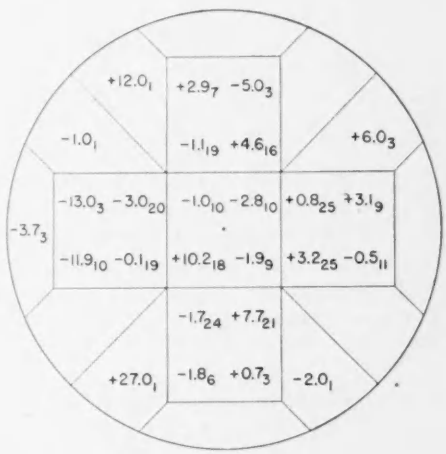

$\rho$ 100-199, $SD_N$ +0.5, $\bar{v}$ ±6.8

N 381, $SD'_N$ +0.2, $\bar{v}_n$ ±2.5




$\rho$ 200-399, $SD_N$ -1.1, $\bar{v}$ ±8.1

N 458, $SD'_N$ -0.4, $\bar{v}_n$ ±3.0




$\rho \geqslant 400$, $SD_N$ +0.9, $\bar{v}$ ±10.1

N 278, $SD'_N$ -0.5, $\bar{v}_n$ ± $3.8^5$

FIG. 6.—Mean systematic values ($v_n$) of $v = C - \delta C - E - C_S$ for stars north of +80° (unit, 0.01 mag.; appended figures [$n$], numbers of stars). Owing to the small values of $n$, $v_n$ is considerably affected by accidental errors in $v$; nevertheless, the persistence of algebraic sign over considerable areas and throughout a wide range in distance indicates the presence of real systematic effects—mostly the combined influence of local zero-point error in the *Catalogue* and of deviations from the mean absorption.

averaged line-of-sight absorption coefficient. The range in $SD_n$ is now small (means for negative and positive values, $-0.016$ and $+0.019$ mag.), but the clustering of signs is even more marked than in Figure 6. A noteworthy point is the distribution of $SD_n$ over the polar cap, which closely resembles that of the magnitude differences discussed in *Mt. W. Contr.*, No. 647.[17] These differences, between photographic values from the *Polar Catalogue* and Hassenstein's photoelectric measures for certain stars, also raised a question of zero-point error. At that time probabilities seemed strongly against the photoelectric results; but the evidence of Figure 7 derived from colors tends now to localize at least part of the magnitude differences in a small variation in the zero point of the *Catalogue*, which, in turn, would, of course, affect the colors. Hence there is reason for believing that the clustering of signs in Figure 7 is at least partly due to zero-point error in $C$.

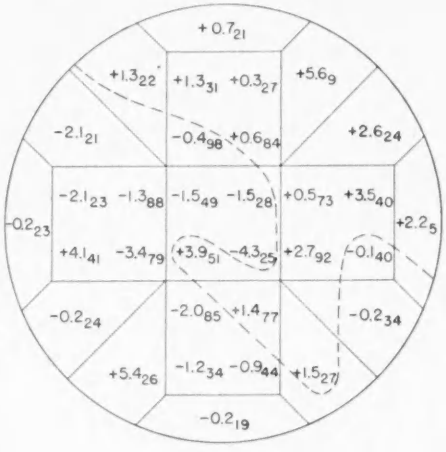



FIG. 7.—Similar to Figure 6, but for stars at all distances. Sampling error is here much reduced. Positive and negative deviations are highly localized, but the average systematic effect (zero point and absorption together) is less than $\pm 0.02$ mag.

At the same time, no permissible variations in zero point will account for some of the values of $SD_n$ in Figure 7—for example, the sequence just below the pole: $+0.041$, $-0.034$, $+0.039$, $-0.043$, $+0.027$ mag., each based on an abundance of stars. The explanation of these fluctuations must lie chiefly in the absorption. Although the two effects cannot be completely separated, their relative importance can be calculated.

The $N$ stars within any distance interval provide $G$ groups (fields) such that $N = n_1 + n_2 + \ldots + n_G$. Write

$\bar{v}$ = AD = arithmetic mean residual for the $N$ stars.

$v_n$ = $SD_n$ = algebraic mean for any group of $n$ stars.

$\bar{v}_n$ = Arithmetic mean of the values of $v_n$ for the $G$ groups.

[17] F. H. Seares, *Ap. J.*, **94**, 21, 1941; see Fig. 1.

If there were no local systematic disturbances, we should have for each group, approximately at least, $v_n = \bar{v}/\sqrt{n}$ and, more exactly for all groups together, the arithmetic mean relation

$$\bar{v}_n = \bar{v}\left(\overline{\frac{1}{\sqrt{n}}}\right) = \bar{v}\sqrt{\frac{G}{N}}, \tag{7}$$

where the third member is a permissible approximation if the range in $n$ is not too large. The residuals $v$ would then fully account for the values of $SD_n$. But, if the residuals include local systematic irregularities $v_s$, $v_n$ will also include a systematic component $v_{sn}$, and $\bar{v}_n$ will then exceed the other members of (7). Owing to the small radical factor, we may disregard the influence of $v_s$ in these members and write simply

$$\bar{v}_{sn}^2 = \bar{v}_n^2 - \bar{v}^2\frac{G}{N}. \tag{8}$$

We now suppose that the $G$ values of $v_{sn}$ follow a gaussian distribution closely enough to permit the use of the relation $\overline{v_{sn}^2} = \pi\bar{v}_{sn}^2/2$. Then from (8)

$$\epsilon_{sn}^2 = \overline{v_{sn}^2} = \frac{\pi}{2}\left(\bar{v}_n^2 - \bar{v}^2\frac{G}{N}\right), \tag{9}$$

where $\epsilon_{sn}$ is the dispersion in $v_{sn}$, the average systematic component of $v$ for a small field.

Starting with $v_n^2$ instead of $v_n$, we obtain a second formula:

$$\epsilon_{sn}^2 = \overline{v_n^2} - \frac{\bar{v}^2}{G}\Sigma\frac{1}{n}. \tag{10}$$

Here again the systematic component in $v$ is disregarded. Moreover, both (9) and (10) give the same weight to all values of $v_n$, whatever the value of $n$; and from neither do we obtain $\epsilon_s$, the true dispersion in the systematic components, which we should really like to have, but only $\epsilon_{sn}$.

To meet some of these objections, we divide $v$ into its accidental and local systematic components,

$$v = v_a + v_s, \tag{11}$$

and attempt to express $\overline{v_s^2} = \epsilon_s^2$ in terms of quantities given in Figure 6. For the $N$ stars within any one of the distance intervals, the algebraic sums of $v_a$ and of $v_s$ are nearly zero; and, since the components of $v$ are not correlated and the distribution of $v$ itself is approximately gaussian,

$$\overline{v^2} = \frac{\pi}{2}\bar{v}^2 = \overline{v_a^2} + \overline{v_s^2}. \tag{12}$$

For any one of the $G$ groups, in analogy with (11), $v_n = v_{an} + v_{sn}$, which gives for all the groups the weighted sum

$$\Sigma n\, v_n^2 = \Sigma n\, v_{an}^2 + \Sigma n\, v_{sn}^2. \tag{13}$$

Since $v_{an} = \overline{v_a}/\sqrt{n}$, we find, with the aid of (12),

$$n\, v_{an}^2 = \bar{v}_a^2 = \bar{v}^2 - \frac{2}{\pi}\overline{v_s^2}. \tag{14}$$

Again, for the $n$ stars of any group write

$$\Sigma v_s^2 = (v_{sn} + r_1)^2 + (v_{sn} + r_2)^2 + \ldots ,$$

where $r_1, r_2, \ldots$, are the residuals of $v_s$ relative to the group mean $v_{sn}$. Since $\Sigma r = 0$,

$$n v_{sn}^2 - \Sigma v_s^2 - \Sigma r^2 . \tag{15}$$

Substituting (14) and (15) into (13), we find

$$\Sigma n v_n^2 = G \bar{v}^2 - \frac{2}{\pi} G \overline{v_s^2} + \Sigma v_s^2 - \Sigma r^2 ,$$

where the summation on the right covers the $N$ stars, that on the left the $G$ groups. Dividing by $N$ and rearranging terms, we have

$$\overline{v_s^2} - \frac{N \overline{r^2}}{N - \frac{2}{\pi} G} = \frac{\Sigma n v_n^2 - G \bar{v}^2}{N - \frac{2}{\pi} G} . \tag{16}$$

The quantities on the right are known, but there is no simple way of finding $\overline{r^2}$. The dispersion in $v_s$ therefore escapes us. The coefficient of $\overline{r^2}$, however, is so nearly unity that we assume it to be such. Now, for all groups together, (15) gives $\overline{v_s^2} - \overline{r^2} = \Sigma n v_{sn}^2 / N = \epsilon_{sn}^2$. Hence, finally,

$$\epsilon_{sn}^2 = \frac{\Sigma n v_n^2 - G \bar{v}^2}{N - \frac{2}{\pi} G} . \tag{17}$$

We thus again have an expression for the dispersion in the average of $v_s$ taken over small fields—a weighted mean dispersion, however, free from the sampling errors affecting (9) and (10). We therefore obtain only a lower limit for the systematic component of $v_s$.

Because of the small number of stars in some of the groups and the varied assumptions underlying (9), (10), and (17), all three formulae have been used for the calculation. The data from Figure 6 and some of the intermediate results are given in the upper half of Table 12, the values of $\epsilon_{sn}$ below. The particular formula used obviously has little influence; all three lead to a clearly marked increase in $\epsilon_{sn}$ with increasing distance.

Since both zero-point errors and deviations from the mean absorption (color excess) may produce local systematic effects, write

$$\epsilon_{sn}^2 = \epsilon_{zn}^2 + \epsilon_{En}^2 . \tag{18}$$

Zero-point errors are independent of the distance, whereas $\epsilon_{En}$ may, and obviously does, increase continuously with the distance. In any event, at zero distance $\epsilon_{En} = 0$. Extrapolating the values of $\epsilon_{sn}$ backward to $\rho = 0$, we find $\epsilon_{zn} = \pm 0.015$ mag. The deviation of $\epsilon_{sn}$, the lower limit, from the true dispersion $\epsilon_s$ depends on the rate at which the systematic component $v_s$ changes within the fields. If the variation is slow, $\overline{r^2}$ will be small, perhaps even negligible. The diagrams of Figures 6 and 7 indicate that the fluctuations for some of the fields are rather rapid; but, whatever the rate for $v_{En}$, the conditions under which the magnitudes (and hence the colors) were determined were such that the zero-point component $v_{zn}$ must vary slowly. There should be little error, therefore, in assuming $\epsilon_z = \epsilon_{zn}$ and adopting

$$\epsilon_z = \pm 0.015 \text{ mag.} , \tag{19}$$

a quantity representing the mean error of the zero point of $C$ for the polar cap as a whole. Near the pole the uncertainty should be smaller, in the lower declinations somewhat larger.

This result agrees well with what may be obtained directly from Figure 7. The dispersion in the systematic differences there shown, which includes both $v_{zn}$ and $v_{En}$, is $\pm 0.024$. Omission of the half-dozen largest values, which certainly are much affected by variations in $E$, fully accounts for the excess over the value of $\epsilon_z$ in (19). We are thus led to believe that the clustering of signs shown in Figure 7 mostly indicates a small progressive change in the zero point of $C$, while the average line-of-sight absorption coefficient, with the exception of the few fields mentioned, remains nearly constant over the whole polar cap.

TABLE 12

DISPERSION IN $E$ AND LOCAL ZERO-POINT ERRORS IN $C$

| $\rho$ | $G$ | $N$ | $\bar{v}$=AD | $\bar{v}_n = SD_n$ | $\bar{v}_n^2$ | $\Sigma n \bar{v}_n^2$ | $\frac{1}{G}\Sigma\frac{1}{n}$ |
|---|---|---|---|---|---|---|---|
| <100 | 30 | 247 | ± 5.7 | ±2.4 | 8.5 | 1772 | 0.151 |
| 100–199 | 32 | 381 | 6.8 | 2.5 | 10.0 | 2514 | .131 |
| 200–399 | 32 | 458 | 8.1 | 3.0 | 12.8 | 4822 | .108 |
| ⩾400 | 26* | 278* | ±10.1 | ±3.8[5] | 28.9 | 7312 | 0.118 |

| $\bar{\rho}$ | $\epsilon_{sn}$ | | | | $\epsilon_{En}$ | $\bar{v}_a$ | $\bar{v}_a - \bar{v}$ |
|---|---|---|---|---|---|---|---|
| | (9) | (10) | (17) | Mean | | | |
| 60 | ±1.7 | ±1.9 | ± 1.9 | ±1.8 | ±1.0 | ±5.5 | −0.2 |
| 150 | 1.9 | 2.0 | 1.7 | 1.9 | 1.1 | 6.6 | .2 |
| 300 | 2.6 | 2.4 | 2.5 | 2.5 | 2.0 | 7.8 | .3 |
| 700 | ±3.4 | ±4.1 | ±4.2 | ±3.9 | ±3.6 | ±9.6 | −0.5 |
| | For $\rho=0$, $\epsilon_{sn}=\epsilon_z=$ ±1.5 | | | | | | |

* The six outer fields, including usually but a single star, are used only for equation (17). The numbers in the last four columns are for the fields actually used.

From (18) and (19) we now find the values of $\epsilon_{En}$ given in Table 12, which, as already explained, may be considerably less than the true dispersion $\epsilon_E$. Further, from (12),

$$\bar{v}_a^2 = \bar{v}^2 - \frac{2}{\pi}\overline{v_s^2}. \qquad (20)$$

By using $\epsilon_{ns}^2 = \overline{v_{sn}^2}$ for $\overline{v_s^2}$, as elsewhere, we find the average accidental component of $v$. For the later discussion it is important to note that the results, also shown in Table 12, are upper limits. Since $\epsilon_{sn}$ is relatively small, $\bar{v}_a$ is nearly as large as $\bar{v}$. The small differences in the last column of the table are used later to obtain values of $\bar{v}_a$.

## X. DISPERSION IN COLOR FOR STARS OF THE SAME SPECTRAL TYPE

The accidental component of a residual $v$ is itself a complex quantity of the form

$$v_a = v_S + v_C + v_d\,, \qquad (21)$$

where

$v_S$ originates in the accidental error of the spectral type (not to be confused with $v_s$ of the preceding section);

$v_c$, in the accidental error of the *Catalogue C*, exclusive of zero-point and magnitude error;

$v_d$, in the dispersion in $C$ for stars of the same type.

The relation $\epsilon_d^2 = \overline{v_d^2}$ determines the dispersion in $C$; hence we are here chiefly interested in the component $v_d$. Since there is no reason to suspect correlation between any of the quantities on the right of (21), we have, for the mean of a group of stars,

$$\overline{v_a^2} = \overline{v_s^2} + \overline{v_c^2} + \overline{v_d^2}. \tag{22}$$

To avoid uncertainties in classification errors, we suppose the spectral types to have been determined by a second observer, thus giving a second equation, similar to (22). Combining the two and replacing each $\overline{v^2}$ by $\pi\bar{v}^2/2$, we have

$$\frac{2}{\pi}\epsilon_d^2 = \bar{v}_d^2 = \tfrac{1}{2}\{\bar{v}_{a1}^2 + \bar{v}_{a2}^2 - \delta^2\} - \tfrac{1}{2}\{\bar{v}_{c1}^2 + \bar{v}_{c2}^2\}, \tag{23}$$

where[18]

$$\delta^2 = \bar{v}_{s1}^2 + \bar{v}_{s2}^2 = (f \cdot \Delta S)^2. \tag{24}$$

The quantity $\Delta S$ (denoted by AE in the tables of the preceding *Contribution*) is the arithmetic mean of the differences in type, $S_1 - S_2$, corrected for systematic and sampling errors; and $f$, the value of one spectral unit in hundredths of a magnitude, is a factor which converts $\Delta S$ into an equivalent difference in $C$. The last parenthesis in equation (23) provides for the application of the equation to two different (but representative) groups of stars whose $C$'s differ in precision. If the spectral data $S_1$ and $S_2$ are complete for any one group, the last term in (23) is, of course, simply $\bar{v}_c^2$.

The residual $\bar{v}_c$ for $C$ may be found from the *Catalogue* data; $\delta$ from the preceding *Contribution* (or by direct calculation for special groups), $f$ from Table 7, and $\bar{v}_a$ from $\bar{v}$ and the differences $\bar{v}_a - \bar{v}$ given in Table 12.

The empirical correction of $\bar{v}$ to obtain $\bar{v}_a$ may at times be a rather crude approximation. The correlation of $\bar{v}_a - \bar{v}$ with $\bar{v}$ applies to the mean $v$ for data from all sources and does not take account of inequalities of precision between different spectral series. Moreover, an extrapolation of the differences is sometimes necessary. The correction, in any event, is small; but the best evidence that the uncertainty is not serious is the accordance of the values for $\bar{v}_d$ found from different groups of data.

The use of equations (23) and (24) obviously demands caution in the rejection of discordant data, especially when different groups of stars are combined; it is essential that such groups be fair samples. On that account many stars that could safely be omitted in deriving $C_s$ and the mean $E$ have been retained for the calculation of $\bar{v}_d$. There are others, however, which clearly are not representative; and, if used, would lead to highly improbable results, for example, the 9 faint HD dG0 stars (notes, Table 5). Even when the observational data are not in doubt, an exceptional star has occasionally been omitted, such as BD 87°41, Pv *m* 8.11; $C$ 1.94 $\pm$0.02 (ME), a giant; HD K0, Bg K2, U K5; $v$ = +0.72, +0.44, +0.27, respectively. The frequency of such objects is low, and their inclusion in small groups would vitiate the calculation more than their omission.

[18] This relation assumes that the accidental classification errors $v_{s1}$ and $v_{s2}$ are not correlated. As pointed out by Butler and Thackeray (*M.N.*, **100**, 450, 1940), the assumption may not be justified if the two observers use different criteria. Such a procedure obviously may lead to a systematic classification difference which changes rapidly with type and is not fully eliminated if only the average amount, taken over a considerable spectral interval, is applied as a correction to the spectral differences. If, however, the differences for a given subtype are corrected by the systematic difference for that particular type, as has generally been done here, any correlation of the accidental errors apparently should be negligible.

For some of the calculations, values of $\bar{v}$ for all the stars of the different types are required. These are given in Table 14, some of them taken directly from Table 10. Others represent either a regrouping of types or the restoration of discordant residuals.

The results of several solutions for $\bar{v}_d$ are given in the last column of Table 13. The six combinations of spectral data which could be used for this purpose are shown in the first column, the numbers of stars and the types in the second. The remaining columns give the data required for equation (23). The subheadings "1st" and "2d" refer to the first and the second of the spectral series appearing in the first column.

Since the groups having two independent spectral classifications for all the stars are small, some control on the influence of accidental errors is necessary. The first solution, for example, based on only 24 stars, uses the residuals and spectral differences for these particular stars. The influence of selection in the residuals, at least, can be checked by

TABLE 13

DISPERSION IN COLOR INDEX
(Unit, 0.01 Mag.)

| Sp Series | Data | $\bar{v}$ | | $\bar{v}_a$ | | $\delta$ | $\bar{v}_c$ | | $\bar{v}_d$ |
|---|---|---|---|---|---|---|---|---|---|
| | | 1st | 2d | 1st | 2d | | 1st | 2d | |
| U–Bg..... | 22 A–K | ± 7.9[5] | ±6.8 | ± 7.6[5] | ±6.5[5] | ± 9.2 | ±1.8 | ±1.8 | ±2.3 |
| | All | 8.0 | 7.7 | 7.7 | 7.4 | ..... | 2.3 | 1.8 | 2.7 |
| HD–Bg..... | 23 B–M | 7.5 | 6.3 | 7.2[5] | 6.1 | 8.3 | 1.3 | 1.3 | 2.9 |
| | All | 6.9 | 6.8 | 6.7 | 6.6 | ..... | 1.7 | 1.8 | 2.6 |
| HD–Y..... | 52 B, A | 6.8 | 4.9 | 6.6 | 4.7 | 7.5 | 1.7 | 1.7 | 1.4 |
| MW–U..... | 20 A–M | 7.1[5] | 7.4 | 6.9 | 7.2[5] | 8.6 | 1.7 | 1.7 | 3.2 |
| HD–U..... | 13 A5 | 5.1[5] | 5.1 | 5.0 | 4.9 | 4.5 | | | 3.3 |
| | 58 F | 5.8 | 5.7 | 5.6 | 5.5[5] | 6.6 | | | 2.5 |
| | 40 dG0–K2 | 7.2 | 6.7 | 6.9 | 6.5 | 8.0[5] | 1.7 | 1.7 | 3.1 |
| | 21 gG5–G8 | 10.0 | 6.6 | 9.5 | 6.4 | 10.2 | | | 3.2 |
| | 20 gK0–K2 | 11.8[5] | 9.2 | 11.1 | 8.8 | 7.1 | | | (6.2) |
| HD–MW... | 15 A, F | 5.6 | 4.9 | 5.4 | 4.7 | 5.1[5] | | | 3.1 |
| | 18 G | 9.6 | 6.6 | 9.1[5] | 6.3[5] | 10.1 | ±1.7 | ±1.7 | 2.9 |
| | 12 K, M | ±14.3 | ±9.6 | ±13.2 | ±9.2 | ±12.6 | | | (±6.8) |
| Mean... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ..... | ±2.77 |

replacing the $v$ for each of the 22 stars by the $\bar{v}$ for the type in question given in Table 14 and then again forming the means. It is in this sense that the second and fourth solutions depend on all the stars. Since the change in $C$ with spectrum (Table 7) depends on the type, it is important in transforming a spectral difference into its color equivalent always to use the appropriate weighted mean value of the factor $f$.

For the last group of solutions both individual residuals and means from Table 13 could be used for HD but not for MW, since all the available MW stars are included in the solution. Duplicate $\delta$'s, however, could be found with the values of $\Delta S$ (AE) taken from the extensive HD–MW comparison in Table 2 of the preceding *Contribution*. Since $\Delta S$ depends on the grouping—whether according to MW or according to HD types—duplicate $\delta$'s were calculated for each grouping and combined. The results average about a fourth larger than those found directly from the types of the individual stars, a detail to be noted later. The values of HD $\bar{v}$ and of $\delta$ given in Table 13 for the last three solutions are the means of these direct and indirect calculations.

The values of $\bar{v}_c$ change slightly with the declinations and magnitudes of the stars used. For example, the 22 stars of the first solution are all in the 87° and 88° zones, whereas those which determine the U $\bar{v}$ used for the second are scattered over the whole

TABLE 14

MEAN RESIDUALS AND AVERAGE ERROR OF CLASSIFICATION
(Units: $v$, 0.01 Mag.; $e$, 0.1 Spectral Class)

| Sp | HD | | | U | | | Bg | | | Y, MW | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $\bar{v}$ | $e$ | No. | $\bar{v}$ | $e$ | No. | $\bar{v}$ | $e$ | No. | $\bar{v}$ | $e$ | No. |
| B6–A4 | ..... | ..... | ... | ± 8.0 | ±1.47 | 75 | ..... | ..... | ... | ± 4.9 | ±0.72 | 52 |
| A0 | ± 7.6 | ±1.12 | 50 | ..... | ..... | ... | | | | | | |
| 2 | 5.4 | 1.21 | 38 | ..... | ..... | ... | ± 6.5 | ±1.67 | 15 | | | |
| 3 | 7.9 | 2.34 | 21 | ..... | ..... | ... | | | | | | |
| 5 | 5.8 | 1.69 | 21 | 7.8 | 1.83 | 27 | | | | | | |
| F0 | 5.4 | 1.66 | 45 | 7.3 | 2.48 | 24 | | | | | | |
| 2 | 6.2 | 1.89 | 25 | 5.8 | 1.64 | 46 | 4.9 | 1.16 | 52 | 4.6 | 1.23 | 16 |
| 5 | 6.7 | 1.74 | 36 | 7.5 | 1.97 | 135 | | | | | | |
| 8 | 6.0 | 1.43 | 38 | 8.3 | 2.13 | 151 | | | | | | |
| dG0 | 6.7 | 1.51 | 18 | 6.4 | 1.28 | 71 | | | | | | |
| 5 | 7.3 | 1.33 | 18 | 7.2 | 1.20 | 46 | 8.1 | 1.77 | 57 | 6.4 | 1.20 | 7 |
| 8 | ..... | ..... | ... | 5.3 | 0.78 | 29 | | | | | | |
| dK0 | 9.0 | 1.46 | 55 | 6.1 | 0.87 | 31 | 11.5 | 1.97 | 4 | | | |
| gG0 | 6.5 | 1.47 | 4 | ..... | ..... | ... | | | | | | |
| 5 | 6.9 | 1.59 | 64 | 7.4 | 1.57 | 65 | 10.3 | 1.81 | 34 | 6.7 | 1.05 | 11 |
| 8 | ..... | ..... | ... | 7.1 | 1.13 | 69 | ..... | ..... | ... | | | |
| gK0 | 14.0 | 1.48 | 68 | 9.9 | 1.03 | 51 | ..... | ..... | ... | 10.3 | 0.80 | 11 |
| 2 | 15.4 | 1.21 | 25 | 10.5 | 0.81 | 18 | ±11.4 | ±1.36 | 10 | | | |
| 5 | 9.4 | ±2.36: | 12 | 9.0 | ±2.41: | 23 | ..... | ..... | ... | ± 8.4 | ±0.80: | 8 |
| M | ±10.6 | ..... | 14 | ±13.2 | ..... | 12 | ..... | ..... | ... | | | |
| Totals | ..... | ..... | 552 | ..... | ..... | 873 | ..... | ..... | 172 | Y 52, MW 53 | | |

NOTES TO TABLE 14

B6–A4 The results in the last division of the table are for Y, with $\bar{v}_d = \pm 1.4$. All others in this division are for MW.

U A5 Exclusion of BD 85°387 (notes, Table 9) and two stars close to the limiting magnitude reduces $\bar{v}$ to $\pm 6.2$, which was used to calculate $e$.

HD dG0 Inclusion of 10 faint stars (notes, Table 5) would increase $e$ to $\pm 2.51$, which is inconsistent with the value of $\Delta S$ in Table 15, second column.

U dG0 For the second U–Bg solution, Table 13, involving faint stars, $\bar{v} = \pm 7.2$ (184 stars) was used for dG0–K2 stars.

HD dK0 The large $\bar{v}$ arises from 9 discordant stars, nearly all close to the limiting magnitude. For Table 13, $\bar{v} = \pm 5.7$ (46 stars) was used, since the discordant stars either do not appear in combinations with other data or affect them but slightly. The value $\pm 9.0$, however, has been used to calculate $e$. The large $\bar{v}_d$, $\pm 6.8$, would give $e = \pm 0.89$, which is inconsistent with $\Delta S$ in Table 15.

U dK0 Includes 10 dK2 stars. The results for these dwarfs, as also for dG8, are remarkably accordant. On the improbable assumption that $\bar{v}_d = 0$, $e$ in both cases would still be less than 1.0.

U gG8 For the second U–Bg solution, Table 13, involving faint stars, $\bar{v} = \pm 8.4$ (73 stars) was used.

gK0–K2 All values of $e$ except that for MW were computed with $\bar{v}_d = \pm 2.6$. Larger values of the dispersion would lead to errors which are incompatible with the results for $\Delta S$ in Table 15 and in Table 2 of the preceding *Contribution*. Although the MW group includes 2 gK3 and 1 gK4, the gK0–K2 types dominate, and the small dispersion might be expected to apply. The residuals, however, are large relative to $\Delta S$ and require a large $\bar{v}_d$, at least $\pm 6.8$ (which was used), to give an $e$ consistent with the $\Delta S$ ($\pm 0.95$) normally to be expected. The small number of MW stars probably accounts for the discrepancy.

HD, U gK5 The $e$'s, for $\bar{v}_d = \pm 6.8$, are too large; a still larger dispersion seems to be required. The solution for $e$, however, is inherently uncertain, owing to the difficulty of finding the rate of change in $C$ with the spectrum corresponding to the particular stars used.

M Since errors in the type contribute but little to $\bar{v}$, $e$ is practically indeterminate, and $\bar{v}$ is mostly dispersion in $C$; $\bar{u}_d$ seems to be of the order of 0.10 or 0.11 mag.

polar cap. The consistency of the *Catalogue* data for these components (they are really values of AE, the average error in $C$) was tested by calculating $\bar{v}_c$ both from the average deviations and numbers of plates used and from the total weights of each of the 24 stars. The results are $\pm 0.0185$ and $\pm 0.0175$ mag., respectively. The value from the table of averaged results on page 48 of the *Catalogue* is $\pm 0.018$ mag., all, of course, exclusive of local zero-point errors and any magnitude error in the color indices, both of which have already been allowed for. The agreement for the 23 stars of the second group is equally good.

The reservation naturally felt in respect to statistical conclusions based on small groups of stars is partially removed by the confirmation found in the results from the mean residuals of Table 14 and the spectral differences of the preceding *Contribution* and, more completely, by the agreement of the values of $\bar{v}_d$ obtained from different groups of spectral data. The only discordant values are the two in parentheses for late-type stars. From the other values of $\bar{v}_d$ we find for the mean dispersion in the color indices of stars of the same type (earlier than K0)

$$\epsilon_d = \pm 0.035 \pm 0.002 \text{ (ME) mag.} \tag{25}$$

This result is, moreover, an upper limit, since the values found for $\bar{v}_a$ are upper limits. Further, if the errors affecting $C$ have been underestimated, the value (25) will for this reason also be too large. To K0 at least, the colors of stars therefore run closely parallel to the normal types defined by the criteria of the Harvard classification system. Stars with peculiar spectra may, of course, show large deviations.

Because of scanty data the evidence on dispersion among K and M stars is inconclusive, but some results given in the next section indicate that the small value may hold as far as type K2. From K4 on, however, general considerations show that the dispersion among the sixty-odd stars for which $C$ is available must be much larger than the value (25). Since for these types the change in color with type is slow, classification errors have little effect on the value of $C_s$ taken from Table 7. The known contributions to $v$ thus fall far short of accounting for the large residuals shown by these stars, and a considerable dispersion in color apparently must be invoked to explain the discrepancy. Although the stars concerned are giants, involving perhaps a considerable range in luminosity, it is unlikely that the ordinary luminosity effect plays any important part in the matter. If it did, we should not expect the dispersion in the gG5–8 stars to be so small as it apparently is (Table 13).

## XI. ACCIDENTAL ERRORS OF SPECTRAL CLASSIFICATION

Denoting the average error (0.8 of ME) of a spectral type by $e$, we have $fe = \bar{v}_s$, a relation which supposes the sampling errors in $v$ to be negligible, as, in fact, they should be, since the residuals are relative to a smoothed spectrum-color curve based on abundant material. Hence, from equation (22), we have

$$f^2 e^2 = \bar{v}_a^2 - \bar{v}_c^2 - \bar{v}_d^2 . \tag{26}$$

Since $\bar{v}_d$ is now known, the classification errors ($e$ expressed in spectral units), can be calculated for the different spectral series with this formula. The results thus found are in Tables 14, 14*a*, and 14*b*, the first of which, as far as possible, gives values of $e$ for each subtype, while the smaller tables include average values of $e$ for the several groups of stars used for Table 13.

The systematic effects of zero-point error and of deviations from the mean absorption, as usual, were removed from $v$ with the aid of the differences in the last column of Table 12. Except as indicated in the notes, $\pm 2.6$ was used for $\bar{v}_d$. The slightly larger value, $\pm 2.8$, finally adopted (Table 13), is the result of some revisions made after

Table 14 had been finished. The differential effect on $e$ is only one or two units of the second decimal, which usually is not significant anyway. The small value of $\bar{v}_d$ is applicable to the dK0 stars and apparently holds for gK0–2. At some point near this limit, however, the dispersion seems to increase rather rapidly, and for M-type stars, as far as can be judged from the present data, reaches a value of about 10 (0.10 mag.).

Certain exceptional values of $e$ are noteworthy—at one extreme those of $\pm 0.7$ to $\pm 0.8$ sp. units for U dG8–K0 and gK2, the Y early types, and MW gK0–2; at the other, values three times as large for HD A3 and U F0. This wide range in $e$ and the sudden jumps in its values, as for U in the interval A5–F2, raise a question as to the reliability of any value of the error found from a small group of stars. The data themselves afford a rather definite answer.

TABLE 14*a*

CLASSIFICATION ERRORS

| No. | Sp. | HD | Res. | U | Res. | No. | HD Sp. | HD | Res. | $e_{MW}/e_{HD}$ |
|---|---|---|---|---|---|---|---|---|---|---|
| 52 | B8–A4* | ±1.07† | −0.05 | | | | | | | |
| 13 | A5 | 1.77 | + .08 | ±1.71 | −0.12 | | | | | |
| 58 | F | 1.75 | + .08 | 1.73 | − .28 | 14 | F | ±1.52 | −0.23 | 0.72 |
| 40 | dG0–K2 | 1.22 | − .20 | 1.11 | + .10 | 10 | dG | 1.56 | + .12 | .83 |
| 21 | gG5–G8 | 1.72 | + .17 | 1.02 | − .34 | 7 | gG5 | 1.94 | + .35 | .62 |
| 20 | gK0–K5 | ±1.28‡ | −0.06 | ±0.83‡ | −0.06 | 13 | gK0 | ±1.57§ | +0.09 | 0.57 |

* Y spectra; the others in this column are U.

† From the stars of the HD–Y group of Table 13, with $\bar{v}_d = \pm 1.4$. Since the HD types of these stars are nearly all A0, the result is compared with that for A0 in Table 14. The other values of $e$ in this table are from the HD–U and HD–MW groups.

‡ Computed with $\bar{v}_d = \pm 6.2$.

§ Computed with $\bar{v}_d = \pm 2.6$.

TABLE 14*b*

CLASSIFICATION ERRORS

| Group | $e$ | Residual from $\bar{v}$ | Residual from $\bar{e}$ | No. Stars | Group | $e$ | Residual from $\bar{v}$ | Residual from $\bar{e}$ | No. Stars |
|---|---|---|---|---|---|---|---|---|---|
| HD | ±1.65 | +0.10 | +0.24 | 23 | U | ±1.24 | − .06 | − .11 | 20 |
| Bg | 1.35 | − .11 | − .16 | | MW | ±1.17 | +0.01 | +0.14 | |
| Bg | 1.50 | − .12 | − .07 | 22 | | | | | |
| U | ±1.81 | + .10 | + .23 | | AD | ..... | ±0.08 | ±0.16 | ..... |

Consider, for example, the mean results from the groups of stars listed in Table 14*a* and in particular the HD value $\pm 1.75$ from the 58 stars of U type F. The corresponding HD types for these stars and their respective numbers are as follows:

| HD | A2 | A3 | A5 | F0 | F2 | F5 | F8 | dG0 |
|---|---|---|---|---|---|---|---|---|
| No. | 2 | 2 | 3 | 10 | 9 | 17 | 11 | 4 |

By assigning to each subtype the corresponding mean $e$ from Table 14, we obtain for the group a weighted mean of $\pm 1.67$. The deviation of the value found directly from what is to be expected for such a group on the basis of the more abundant material in Table 14 (in this case 242 stars) is thus +0.08.

The other residuals in Tables 14*a* and 14*b* have a similar significance, except those of the third column of Table 14*b*, for which the expected error is based, not on values of

$C$ from Table 14, but on the corresponding $v$'s. Residuals based on $e$ are also given, however (fourth column). The two series do not agree exactly, since the weighting factors are applied in one case to $v$, in the other to $e$, quantities connected by a nonlinear relation. The different values of $e$ for the same spectral series—for example, the pairs for Bg and for U in Table 14*b*—are not comparable, since different spectral distributions are involved in the groups to which they refer.

The U residuals in Table 14*a* are mostly negative, and two of them large. The corresponding errors printed in this table are for groups of stars which also occur in the HD, whereas the values based on Table 14 with which they are compared refer to stars whose limiting magnitude is much fainter. The systematic difference in the residuals merely reflects the larger classification error affecting faint stars. The large residuals in the last column but one of Table 14*a*, for 14 and 7 stars, respectively, are not surprising. The ratios of the MW and HD errors (averages from different methods of calculation) found from the same group of 44 stars are in the last column of the table.

The general indication of Tables 14*a* and 14*b* is that the value of $e$ found from a group of 25 or 30 stars should be correct within 0.1 or 0.2. Hence the more conspicuous differences in $e$ shown in Table 14 apparently should be real, although it may be questioned whether the exceptional values for HD A3 and U F0 are representative of what would be given by larger groups of stars.

In general, the errors for F stars are high, with a gradual drift toward lower values in both directions in the spectral series. For the A's, U averages a little larger than HD, but for G and early K stars the opposite holds. The precision for the U late-type dwarfs is consistently higher than for the corresponding giants. The evidence for any similar inequality in the HD results is inconclusive. The low value $e = 0.72$ for Y, mean type A0, 0.68 of the corresponding HD result, is well determined. The MW errors range from 0.6 to 0.8 of the HD values (Table 14*a*).

In section ii of the preceding *Contribution* it was found that the errors of the spectral differences HD − MW reflect the inequalities of interval in the HD classification scale as commonly used. This correlation should also appear in the HD and the U errors of Table 14 and, in fact, can be detected in these errors, but less clearly than in the values of $\Delta S$. In Table 14 the relationship is somewhat blurred, since $e$ is calculated from $v$, which includes several disturbing influences besides the one now in question.

The low average $e$ for MW is, of course, to be expected because of the favorable observing conditions, but the small number of stars leaves the individual values open to doubt. It is possible, theoretically at least, to calculate errors for MW from the values for HD in Table 14 and the mean spectral differences, $\Delta S$, by the relation[18]

$$e_{\mathrm{MW}}^2 = (\Delta S)^2 - e_{\mathrm{HD}}^2 . \tag{27}$$

For clarity consider the gK0 stars. Grouped according to HD types, the spectral differences give (Table 2, preceding *Contribution*)

$$\Delta S = \overline{\mathrm{MW}} - \mathrm{HD} = \pm 2.4 , \tag{28}$$

while, for the alternate grouping,

$$\Delta S = \overline{\mathrm{HD}} - \mathrm{MW} = \pm 0.8 . \tag{29}$$

The latter relation shows that nearly all the MW gK0 stars appear in the HD as K0; but from equation (28) it follows that HD K0 also includes many stars of other MW types. Since the value (29) does not cover the entire range in the HD error, (28), for the HD grouping, must be used with (27). Further, since the HD errors in Table 14 also correspond to HD types, the quantities to be substituted into (27) are homogeneous.

The necessary data and the MW $e$'s thus computed are in the first six columns of Table 15. For comparison the MW errors already found are shown in the seventh column. For the F's and gK2 the agreement is reasonably satisfactory, but for all the intermediate types the computed values are much too large—most clearly so for gK0, since relation (29) shows that for this type MW $e$ is certainly less than $\pm 0.8$. In other words, the "computed" $e$ is nearly 2.5 times the largest permissible value.

The origin of the discrepancy is easily found. Since $e_{MW} < 0.8$, the value (28) gives $e^2_{HD} > (2.4)^2 - (0.8)^2$, or $e_{HD} > \pm 2.26$, a result for the stars at large (those listed in *Mt. W. Contr.*, No. 511). From Table 14, however, $e_{HD} = \pm 1.48$, a value based on polar stars alone. The difference is too large to be accounted for by any statistical uncertainty. The explanation seems to be a higher precision in the HD classifications for stars near the pole than for stars at large.

TABLE 15

COMPUTED MW ERRORS

| HD Sp | $\overline{MW}-HD$ | | HD | | Comp. MW $e$ | MW, Table 14 | | | $\overline{HD}-MW$ | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $\Delta S$ | No. | $e$ | No. | | $e$ | $\overline{Sp}$ | No. | $\Delta S$ | No. |
| A5 | $\pm 1.8$: | 45 | $\pm 1.34$ | 130 | $\pm 1.20$: | | | | | |
| F0–8 | 2.1 | 360 | 1.65 | 144 | 1.30 | 1.23 | F3 | 16 | $\pm 2.0$ | 343 |
| dG0 | 2.4 | 182 | 1.51 | 18 | 1.86 | | | | 1.7[a] | 60 |
| dG5 | 3.2 | 203 | 1.33 | 18 | 2.91 | 1.20 | G4 | 7 | 2.0 | 39 |
| dK0 | 2.9 | 112 | 1.46 | 55 | 2.51 | | | | 2.5 | 28 |
| gG5 | 2.8 | 138 | 1.59 | 64 | 2.30 | 1.05 | G6 | 11 | 2.1 | 32 |
| gK0 | 2.4 | 388 | 1.48 | 68 | 1.89 | <0.80* | | | 0.8 | 73 |
| gK2 | $\pm 1.4$ | 80 | $\pm 1.21$ | 25 | $\pm 0.71$ | 0.80 | K2 | 11 | $\pm 0.5$ | 67 |

* From equation (29).

The argument holds for all the other types except F0–8, for which $\Delta S = \overline{HD} - MW = \pm 2.1$ is well in excess of the computed $e$. With this exception, therefore, the computed errors are all too large, even that for gK2 (subject, however, to the uncertainty inherent in a group of 25 stars). And with this same exception of the F stars, the conclusion in respect to the higher precision of the HD classification for polar stars also holds. Incidentally, the difference appears clearly in the 53 stars for which both HD and MW types are available. It has already been met in the $\delta$'s for 45 of them (p. 295); and now from the entire group of 53 we find $\Delta S = \pm 1.68$, whereas from the extensive comparison of the preceding *Contribution* we should expect, for the same spectral distribution, $\Delta S = \overline{MW} - HD = \pm 2.24$. These values, of course, include the MW errors, but from the foregoing discussion it is clear that the difference originates in the HD.

## XII. STARS SHOWING EXCEPTIONAL DISCORDANCES IN COLOR

Numerous instances of discordant residuals are listed in the notes to Tables 5 and 9, most of which, for one reason or another, may be regarded as indicating only exceptional errors of observation. Among them, however, are some that suggest either a peculiarity in the star or a deviation from the mean space absorption and hence may prove to be of special interest. For convenience the more promising of these objects are noted here. For some of them, observation error may, of course, still be the explanation. The residuals, as usual, have been freed from absorption.

8 U A, F stars and BD 86°262, gG5 (notes Table 9), all showing a $v$ of about +0.3 mag.

12 U G, K stars (notes, Table 5), 7 with $v > +0.3$ mag. For a type as late even as M, the color of BD 82°504, gK2, $v = +0.39$, would still be high.

BD 88°12, 88°19, 88°38, all Bg G8 (notes, Table 5); $v \geqslant +0.4$ mag.

Among the HD gK0 stars (notes, Table 9), BD 80°451, 80°468, 84°225, 85°3, $v = +0.3$ to $+0.5$ mag., are noteworthy.

BD 87°41, Pv *m* 8.11, *C* 1.94 ±0.02 (ME), a giant, of more than usual interest. Types and residuals are HD K0 +0.7, Bg K2 +0.4, U gK5 +0.3.

BD 85°297, Pv 9.61, U gK0. The *Catalogue C*, 2.35, is very uncertain, since Pg *m* depends on a single plate. There is little doubt, however, that the star is exceptionally red for the type assigned.

Of the 27 M-type stars for which colors and types are available (7 with duplicate classifications), 11 require comment: First, the exceptionally red stars BD 81°67 HD Ma, BD 82°28, 83°500, 85°100, all U gM; for all 4 stars $v \geqslant +0.2$ mag. The remaining stars, 5 U gM, followed by 2 U gMb, are given in the accompanying tabulation. The

| BD | *C* | *C*−*E* | BD | *C* | *C*−*E* | BD | *C* | *C*−*E* |
|---|---|---|---|---|---|---|---|---|
| 84°141 | 1.42 | 1.15 | 86° 84 | 0.92 | 0.65 | 84°240 | 1.02 | 0.75 |
| 84 263 | 0.96 | 0.69 | 86 238 | 1.35 | 1.08 | 84 516 | 1.18 | 1.00 |
| 85 114 | 1.27 | 1.00 | | | | | | |

last star, also HD Mb, Pv *m* 7.50, is the irregular variable AR Cephei, amplitude 0.8 mag., which was included in the *Catalogue* by mistake. Since Pg and Pv magnitudes do not refer to the same epoch, *C* may be considerably in error.

With allowance for absorption, these seven stars are from 0.4 to 0.8 mag. bluer than normal gM's. Except for BD 84°516, Pv *m* is between 10.3 and 10.7; nevertheless, gross classification errors are scarcely to be expected, and the stars seem to be in a class by themselves. Low luminosity apparently does not explain the discrepancy, since dwarf and normal giant M's, in some cases at least, have nearly the same color.[19] It seems likely that the stars are late M types in which the absorption bands are so highly developed that the mean effective wave length lies to the violet of that for normal gMa (MW gM2)

[19] F. H. Seares, *Mt. W. Comm.*, No. 59; *Proc. Nat. Acad.*, 5, 232, 1919. The measurements by exposure ratios, some of them unpublished, include 6 Ma and 1 Mb dwarfs of about $M = +10$. The agreement in color with the normal giants of these types is within the uncertainty of measurement.

# EFFECTIVE WAVE LENGTHS OF STANDARD MAGNITUDES; COLOR TEMPERATURE AND SPECTRAL TYPE*

FREDERICK H. SEARES[1] AND MARY C. JOYNER
Mount Wilson Observatory
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## ABSTRACT

The investigation is concerned primarily with (*a*) the derivation of effective wave lengths, $\lambda_{Pg}$, $\lambda_{Pv}$, for the color system of the international Pg and Pv magnitudes; (*b*) calculation, for a series of temperatures, of black-body color indices $C$ corresponding to $\lambda_{Pg}$ and $\lambda_{Pv}$; (*c*) derivation of color temperatures (of black-body radiators) corresponding to observed color indices for the standard spectral types B5, A0, etc. For control and comparison, similar calculations were also made for the Pe and $C_1$ and $C_2$ systems of Stebbins.

*The international system of color.*—This is determined by sensitivity factors of the form $s = f(\lambda) = \tau r^2 p$, where $\tau$ = atmospheric transmission at the altitude of the pole, $r$ = coefficient of reflection of silver ($r^2$, since two reflections are involved), and $p$ = sensitivity factor of the plate—the Seed 27 for Pg magnitudes, the Instantaneous Iso exposed behind a certain filter for Pv.

*The effective wave length.*—This is the ordinary weighted mean $\lambda_e = \Sigma\lambda sy/\Sigma sy$, where $y$ (Table 1) for a given temperature, also a function of $\lambda$, is proportional to the intensity of radiation of wave length $\lambda$.

There is no direct determination of $p$ for either of the standard plates. Mees's values for the Eastman 40 have been used, instead, for Pg *m*, and for Pv *m* a series obtained from low-dispersion spectrograms of northern skylight. Results for $\lambda_e$ and for the corresponding theoretical color indices are given in Table 3. Alternative values for aluminized mirrors are in Table 4.

*Effect of atmospheric extinction.*—Calculated values of the extinction at the pole and the zenith for stars of different temperatures are given in Tables 5 and 6. The dependence on temperature is important, especially for Pg magnitudes, and should not be neglected, as is done in current photometric practice.

*Ratio of total Pg absorption to color excess.*—Values computed from the effective wave lengths of Table 3 for an absorption varying as $\lambda^{-1}$ are listed in Table 7. This table also gives, for the same absorption law, the influence of stellar temperature on color excess.

*Reduced color-spectrum relation.*—The values of $C_S$ (Table 7 of the preceding *Contribution*) may be freed from the differential effects of stellar temperature on color excess and on atmospheric extinction by means of the corrections in Tables 9 and 9*a*.

*Color temperatures.*—The reduced values of $C_S$ and the black-body color indices of Table 3 for different temperatures lead to the color temperatures in Tables 10 and 11. The zero point is fixed by adopting 11,000° K for type A5. The results from the photoelectric colors $C_1$ and $C_2$ agree well but are systematically lower than those from the international $C$. For gK0 the values are 3750° ± 64° (ME) and 4150° ± 80°, respectively. The difference of 400° probably arises from departures from black-body radiation in the stars (sec. xi).

*Miscellaneous.*—In section vi it is shown that for all practical problems the absorption $A = \rho\lambda^{-1}$ calculated by the direct substitution of the effective wave length $\lambda_e$ is the same as that found by integrating the losses over the entire range in $\lambda$ (Table 8). The same is also true for Rayleigh scattering in amounts comparable with the atmospheric extinction (up to 0.6 mag. at the pole).

The use of sensitivity factors for the Eastman 40 plate instead of those for the Seed 27 and several other approximations are discussed in detail in section ix. None of the errors thus introduced can account for the systematic difference in the color temperatures found for the international and the photoelectric systems. The influence of observational errors in $C$, $C_1$, and $C_2$ on the adopted temperatures is examined in section x. The relationship of Brill's isophotal wave lengths to the effective wave lengths of Table 3 is discussed in section xiii (cf. Table 12).

## I. GENERAL RELATIONS

For the following discussion Planck's radiation equation, which in some form or other is an essential, has been replaced by its canonical transformation.[2] The substitution

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 685.

[1] Research Associate, Carnegie Institution of Washington.

[2] See, e.g., C. Fabry, *Introduction générale à la photométrie*, p. 120, Paris, 1927.

$x_1 = \lambda T/c_2$ reduces the right member of Planck's equation to a product of two factors, one proportional to $T^5$, the other an exponential in $x_1$, denoted by $y_1$. Changes in units such that $x = x_1/x_m$, $y = y_1/y_m$, where $x_m$, $y_m$, are the co-ordinates of the maximum of $y_1 = f(x_1)$, then give

$$\left.\begin{aligned} \lambda_m = 2886/T\,, \qquad x = \lambda/\lambda_m\,, \qquad y = x^{-5}/(e^{1/x}-1)\,, \\ I = 1.301\left(\frac{T}{1000}\right)^5 y = T'y\,. \end{aligned}\right\} \tag{1}$$

The coefficient 2886 corresponds to the value 1.433 cm deg for Planck's $c_2$ constant. This expression for $I$, the intensity of black-body radiation of temperature $T$ and wave length $\lambda$, in watts per square centimeter, has the advantage that $y$, although implicitly a function of both $T$ and $\lambda$, depends formally only on $x$ and can be tabulated as a function of this single variable, as has been done by Fabry.[2] An awkward calculation is thus replaced by an interpolation from a single-argument table.

For comparisons with observed data, $I$ (or $y$) must be multiplied by a sensitivity factor $s$, comprised usually of a number of subfactors, such as the atmospheric transmission, the transmission of an objective, or the reflection coefficient of a mirror, and the sensitivity of a photographic plate or a photocell.

For a star of temperature $T$ (radiating as a black body by assumption), the total observed energy thus becomes

$$\left.\begin{aligned} e = T'\int s\,y\,d\lambda = T'\Sigma\, s\,y \\ \text{or} \qquad m = -2.5\,\log\,(T'\Sigma\, s\,y)\,. \end{aligned}\right\} \tag{2}$$

In practice numerical summation must be used rather than integration. The limits are determined by the interval in $\lambda$ within which $s$ differs from zero.

If sensitivities $s_B$ and $s_Y$ are known for two spectral regions, "blue" and "yellow," respectively, the theoretical (black-body) color index, $m_B - m_Y$, for temperature $T$, may be found from

$$C_{BY} = -2.5\,\log\,\Sigma\, s_B y + 2.5\,\log\,\Sigma\, s_Y y\,. \tag{3}$$

The radiation involved in producing the magnitude $m$ defined by the second of formulae (2) may be characterized by a single equivalent or effective wave length $\lambda_e$. As the most useful form we adopt the ordinary weighted mean. For magnitudes $m_B$ and $m_Y$, the corresponding effective wave lengths are, accordingly,

$$\lambda_B = \frac{\Sigma\lambda\, s_B y}{\Sigma\, s_B y}\,, \qquad \lambda_Y = \frac{\Sigma\lambda\, s_Y y}{\Sigma\, s_Y y}\,. \tag{4}$$

To connect color index with effective wave length and temperature, we may equate the total observed energy given by formulae (2), of effective wave length $\lambda_e$, to an equivalent amount of black-body radiation of this same wave length. We thus write

$$e_B = k_B I_B\,, \qquad e_Y = k_Y I_Y\,, \tag{5}$$

in which the $I$'s have the values given by equations (1) for $\lambda = \lambda_B$ and $\lambda_Y$, respectively, and the $k$'s are factors chosen to satisfy the equalities. Substituting from formulae (1) and (2), we find

$$k_B = \frac{\Sigma\, s_B y}{y_B}\,, \qquad k_Y = \frac{\Sigma\, s_Y y}{y_Y}\,. \tag{6}$$

The temperature factor, obvious in formulae (2) and still present in (5), has disappeared from (3), (4), and (6). Nevertheless, the values of $C$, $\lambda_e$, and $k$ all refer to a spe-

cific temperature $T$, since $T$ is implicitly involved in all the $y$'s. As will appear later, the variation of the $k$'s with $T$ is slow and the total percentage change is always moderate.

Finally, equations (3) and (6) give, as an alternate to (3),

$$C_{BY} = -2.5 \log k_B y_B + 2.5 \log k_Y y_Y . \qquad (7)$$

Here, as in equation (3), the zero point is arbitrary, and a constant is still to be added for reduction to the usual convention.

If $C$ itself is to be calculated, equation (3) is simpler than (7); but if effective wave lengths—say, values of $\lambda_Y$—are to be found from $\lambda_B$ and $C$, then (7) is to be used. The solution for this case is not indeterminate, as the formula suggests (besides the unknown constant, an unknown $y_Y$ for each $y_B$). The saving circumstance is that even a slight error in the constant produces large irregularities in $\lambda_B$, which must vary progressively. Simple approximations therefore give all the unknowns with accuracy.

All this, however, presupposes knowledge of $k_Y$ or of some similar quantity. If nothing better offers, the small changes in $k_Y$ for $T$ between 5000° or 6000° and, say, 15,000° can be neglected. The results for this temperature range determine the general behavior of $\lambda_Y$, and an extrapolation of the ends of the nearly linear curve will give at least an approximate solution. Data on $k$ can also be obtained from Table 3, as will be seen later.

If the sensitivity factors $s_B$ and $s_Y$ are true transmission coefficients or if $s_B = f\tau_B$, $s_Y = f\tau_Y$, where $\tau$ is the transmission coefficient and $f$ a factor independent of $\lambda$, the foregoing equations completely define the theoretical relations between magnitude, color index, and temperature and fix the zero point of $C$ in relation to $T$. And if, in addition, $C$ has been observed for stars of known spectrum under conditions such that the same sensitivity factors operate, the relation of temperature to spectral type is also determined without further assumption. These special cases afford so-called absolute determinations of temperature.

Usually, however, the proportionality condition for the $s$ factors will not be satisfied, and, as here, zero-point relations must be adopted. On the international scale $C = 0$ for HD spectrum A5; and the temperature for A5 stars seems to be not far from 11,000°.[3] Constants are therefore used which reduce all color indices, color equations, etc., and all values of log $k$ to zero for 11,000°. Any error in this zero-point temperature can easily be corrected when the evidence warrants a change.

As already noted, the temperature factor $T'$ has disappeared from the essential formulae, and the $y$'s alone are needed for the calculations. Values for a sequence of temperatures and a range in wave length ordinarily sufficient, interpolated from Fabry's table, are given here in Table 1.

## II. OBSERVATIONAL DATA

The observations used are, first, photographic (Pg) and photovisual (Pv) magnitudes and color indices ($C$), on the international system, of stars in the polar region, especially those of the North Polar Sequence (NPS); and, second, the photoelectric (Pe) magnitudes and colors ($C_1$, $C_2$) obtained by Stebbins and his associates at Madison and at Mount Wilson.

Owing to the diversity in observing conditions, a rather complicated notation is needed to account for them all. But first, two general statements, not reflected by the symbols used, are required: (1) The published photoelectric magnitudes and colors are reduced to zero air mass. The corrections used varied somewhat from night to night, but the small differential extinction depending on stellar temperature was neglected. The effect on the $C_1$ and $C_2$ colors of stars of 4000° and 11,000° temperature, observed at the

[3] See, e.g., *Greenwich Observations of Colour Temperatures of Stars* (1932) and revision of zero point for these observations by Greaves, Davidson, and Martin, *M.N.*, **94**, 488, 1934; also R. A. Sampson, *M.N.*, **90**, 636, 1930; W. Becker, *Veröff. Univ. Sternw. Berlin-Babelsberg*, **10**, Part VI, 1935.

zenith, is about 0.01 mag., and proportionally larger for larger air masses. (2) All the Pg and Pv magnitudes and the *C* colors considered here refer to the zero point of the visual measures of a few NPS stars as given in *Harvard Circular*, No. 170.[4] Actually, most recent measurements in the polar region, including all the Mount Wilson observations, are based directly on international magnitudes of NPS stars; but these in turn depend on

TABLE 1

VALUES OF $y = x^{-5}/(e^{1/x} - 1)$

| λ | 3,000° | 3,500° | 4,000° | 5,000° | 6,000° | 7,000° | 9,000° | 11,000° | 13,700° | 17,000° | 22,000° |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0.30 | 0.0059 | 0.0263 | 0.0743 | 0.2667 | 0.5263 | 0.7608 | 0.9885 | 0.9588 | 0.7688 | 0.5308 | 0.2919 |
| .31 | .0083 | .0347 | .0928 | .3083 | .5776 | .8046 | .9969 | .9380 | .7333 | .4963 | .2682 |
| .32 | .0115 | .0448 | .1135 | .3510 | .6269 | .8440 | .9999 | .9143 | .6981 | .4639 | .2466 |
| .33 | .0155 | .0566 | .1367 | .3946 | .6740 | .8787 | .9982 | .8885 | .6637 | .4340 | .2271 |
| .34 | .0204 | .0702 | .1619 | .4390 | .7185 | .9086 | .9922 | .8615 | .6303 | .4056 | .2094 |
| .35 | .0264 | .0856 | .1895 | .4831 | .7598 | .9340 | .9825 | .8335 | .5980 | .3788 | .1931 |
| .36 | .0335 | .1029 | .2188 | .5268 | .7977 | .9549 | .9697 | .8049 | .5672 | .3544 | .1783 |
| .37 | .0418 | .1220 | .2496 | .5696 | .8323 | .9713 | .9548 | .7760 | .5376 | .3316 | .1647 |
| .38 | .0514 | .1429 | .2818 | .6112 | .8636 | .9836 | .9376 | .7473 | .5093 | .3104 | .1526 |
| .39 | .0623 | .1654 | .3152 | .6513 | .8914 | .9923 | .9182 | .7188 | .4826 | .2906 | .1416 |
| .40 | .0746 | .1895 | .3495 | .6896 | .9157 | .9977 | .8976 | .6905 | .4569 | .2722 | .1315 |
| .41 | .0883 | .2151 | .3845 | .7260 | .9367 | .9999 | .8760 | .6629 | .4327 | .2551 | .1222 |
| .42 | .1032 | .2419 | .4197 | .7602 | .9544 | .9992 | .8538 | .6359 | .4101 | .2392 | .1135 |
| .43 | .1195 | .2697 | .4551 | .7921 | .9688 | .9957 | .8308 | .6098 | .3883 | .2246 | .1056 |
| .44 | .1372 | .2985 | .4903 | .8217 | .9802 | .9898 | .8075 | .5844 | .3678 | .2111 | .0985 |
| .45 | .1560 | .3282 | .5253 | .8489 | .9889 | .9817 | .7839 | .5597 | .3482 | .1982 | .0919 |
| .46 | .1761 | .3584 | .5596 | .8737 | .9950 | .9719 | .7604 | .5361 | .3301 | .1863 | .0858 |
| .47 | .1973 | .3890 | .5931 | .8961 | .9986 | .9608 | .7370 | .5134 | .3132 | .1753 | .0801 |
| .48 | .2195 | .4198 | .6257 | .9161 | .9999 | .9483 | .7139 | .4915 | .2969 | .1650 | .0750 |
| .49 | .2425 | .4508 | .6576 | .9337 | .9992 | .9343 | .6909 | .4705 | .2817 | .1556 | .0702 |
| .50 | .2663 | .4818 | .6881 | .9491 | .9965 | .9191 | .6680 | .4502 | .2672 | .1469 | .0658 |
| .51 | .2908 | .5125 | .7174 | .9622 | .9919 | .9032 | .6457 | .4309 | .2537 | .1385 | .0618 |
| .52 | .3160 | .5427 | .7452 | .9730 | .9857 | .8867 | .6241 | .4123 | .2410 | .1307 | .0580 |
| .53 | .3417 | .5724 | .7719 | .9819 | .9780 | .8696 | .6031 | .3948 | .2288 | .1235 | .0545 |
| .54 | .3678 | .6015 | .7968 | .9890 | .9692 | .8521 | .5827 | .3779 | .2175 | .1168 | .0513 |
| .55 | .3941 | .6301 | .8204 | .9943 | .9595 | .8342 | .5628 | .3618 | .2068 | .1104 | .0483 |
| .56 | .4206 | .6579 | .8424 | .9979 | .9488 | .8161 | .5432 | .3465 | .1968 | .1044 | .0455 |
| .57 | .4472 | .6847 | .8629 | .9997 | .9369 | .7978 | .5242 | .3317 | .1873 | .0989 | .0429 |
| .58 | .4737 | .7105 | .8818 | .9999 | .9241 | .7794 | .5059 | .3178 | .1781 | .0937 | .0405 |
| .59 | .5001 | .7353 | .8993 | .9988 | .9107 | .7611 | .4881 | .3046 | .1695 | .0889 | .0383 |
| 0.60 | 0.5263 | 0.7590 | 0.9151 | 0.9963 | 0.8969 | 0.7429 | 0.4710 | 0.2916 | 0.1615 | 0.0843 | 0.0363 |

the original Harvard magnitudes,[5] which are zenith values on the system of the *Revised Harvard Photometry*. The reduction to the zenith was made, as usual, by corrections

[4] F. H. Seares, *Mt. W. Contr.*, No. 97, p. 16; *Ap. J.*, **41**, 221, 1915; *Trans. I.A.U.*, **1**, 75, 1922.

[5] The origin of these magnitudes is explained in a letter from Professor E. C. Pickering, dated November 18, 1912, from which I quote, since there seems to be no other statement so explicit: "The scale of magnitudes for the Polar sequence is intended to be the same as that of the *Revised Harvard Photometry* for stars of Class A. . . . . The *Harvard Photometry* scale depends on a hundred circumpolar stars whose mean magnitude was made to coincide with that of Argelander. See *H.A.*, **14**, page 68. The closeness of the agreement is shown in *H.A.*, **14**, pages 360 and 362; see also 356. Our measures are all corrected for atmospheric absorption to reduce them to the zenith, but this is important only if we wish to compare them with some terrestrial absolute standard. All our magnitudes, north and south, refer to stars seen under the same conditions. Argelander applied no correction to his magnitudes for atmospheric absorption, and, of course, we cannot do so for his work, but in Germany the circumpolar stars would culminate near the zenith. If an absolute scale was to be established independently of the work already done, we should naturally expect that the zero would be defined, not for a star in the zenith, but for a star outside the atmosphere. Does this answer your question? I wish it had come a little earlier, and I would then have discussed it at length in the recently published *H.A.*, **64**, No. 8."

which were the same for all stellar temperatures; the differential effect for hot and cool stars, thus neglected, still remains in the NPS standards.

In general, therefore, Pg and Pv magnitudes based on these standards, as well as the standards themselves, refer back to the zero point of the *Revised Harvard Photometry;* but, more important, they include the full amount of the differential extinction depending on temperature for the altitude of observation, which for the standards is that of the Mount Wilson pole.[6] The matter is discussed further in section iv. We turn now to the observations themselves.

*Photographic and photovisual data.*—With a minor exception, all Mount Wilson measurements for the standardization of NPS stars were made with the 60-inch telescope and involve two reflections from silvered mirrors. Seed 27 plates were used for Pg magnitudes, Cramer Instantaneous Isos exposed behind a yellow filter for Pv. All other observations[7] used for the international standards were reduced to the color system thus defined—a procedure also followed in preparing the *Mount Wilson Polar Catalogue,*[8] which is the principal source of data for the adopted relation between color index and spectral type.

For these data we use the symbols

$$\mathrm{Pg}_{27s}\,, \qquad \mathrm{Pv}_{is}\,, \qquad C_{\mathrm{PgPv}}\,, \qquad \text{or simply } C\,, \tag{8}$$

where the subscripts 27 and $i$ indicate the plate brands and $s$ silvered mirrors (two reflections). Since the observed magnitudes and colors include the differential extinction, any calculated values used in comparisons with the observations must be based on sensitivity factors which include the Mount Wilson transmission coefficients for the altitude of the pole (air mass = 1.788; third column, Table 2).

*Photoelectric measures.*—*a*) Observations with the 15-inch Madison refractor[9] and photocell QK302. Heavy filters 1B and 1Y determine the $C_1$ color system. The results are denoted by

$$\mathrm{Pe}_{mr}\,, \qquad C_1 = \mathrm{Pe}_{1\mathrm{B}mr} - \mathrm{Pe}_{1\mathrm{Y}mr}\,. \tag{9}$$

The subscript $m$ refers to the photocell, used only at Madison, and $r$ to the true transmission of the refractor. The magnitudes whose difference is $C_1$ are not observed; they appear as a definition of $C_1$ and must be computed when the theoretical color is required. Then, however, the unknown $r$ must be replaced by $r'$, an approximation of somewhat doubtful accuracy. Sensitivity factors which include $r'$ are given in Table II of the publication cited.[9]

*b*) Observations with the Mount Wilson 100-inch telescope,[10] silvered mirrors, and photocell QK31-2. Filters 2B and 2Y determine the $C_2$ color system. Observed results are expressed by

$$\mathrm{Pe}_{ws}\,, \qquad C_2 = \mathrm{Pe}_{2\mathrm{B}ws} - \mathrm{Pe}_{2\mathrm{Y}ws}\,, \tag{10}$$

where $w$ denotes the cell used at Mount Wilson, in distinction to the Madison cell ($m$). Since the latter alone has been calibrated, we are obliged to use the sensitivities for $m$ in

[6] This is true, e.g., of the *Mount Wilson Catalogue of Selected Areas, Carnegie Inst. Pub. 402,* 1930. Since no explicit statement appears in the *Catalogue,* it may be said here that the polar comparison plates, which fixed the zero points for individual areas, were reduced, not to the zenith, but to the altitude of the pole, because the magnitudes of the polar standards were already zenith values. Temperature corrections, of course, could not then be applied.

[7] *Trans. I.A.U.,* **1,** 75, 1922.

[8] Seares, Ross, and Joyner, *Magnitudes and Colors of Stars North of +80°, Carnegie Inst. Pub. 532,* 1941.

[9] Stebbins and Huffer, *Pub. Washburn Obs.,* **15,** 217, 1934.

[10] Stebbins and Whitford, *Mt. W. Contr.,* No. 547; *Ap. J.,* **84,** 132, 1936.

computing values of equation (10). Although the color response of the two cells is "nearly the same," $m$ should replace $w$ in the symbols for the computed results. Sensitivity factors which include $m$ are in Table 1 of the publication cited.[10]

TABLE 2

TRANSMISSION AND REFLECTION COEFFICIENTS, SENSITIVITY-CURVES

| λ | τ, TR. COEFF.* | | REFL. COEFF.† | | SENS.‡ E40 | DENS. ISO | O−C ZENITH τ λ$^{-4}$ LAW |
|---|---|---|---|---|---|---|---|
| | Zenith | NP | *Ag* | *Al* | | | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) |
| 0.30 | 0.166 | ..... | 0.006 | 0.689 | 0.49 | ..... | −0.211 |
| .31 | .329 | ..... | ..... | .697 | 0.54 | ..... | − .099 |
| .32 | .456 | 0.240 | ..... | .703 | 0.61 | ..... | − .020 |
| .33 | .521 | .312 | .04 | .709 | 0.68 | ..... | .000 |
| .34 | .565 | .361 | .35 | .715 | 0.76 | ..... | + .002 |
| .35 | .605 | .407 | .490 | .721 | 0.84 | ..... | + .005 |
| .36 | .650 | .452 | .560 | .727 | 0.94 | ..... | + .015 |
| .37 | .669 | .495 | .615 | .732 | 0.99 | ..... | + .001 |
| .38 | .705 | .535 | .656 | .736 | 1.00 | ..... | + .008 |
| .39 | .742 | .570 | .695 | .739 | 0.98 | ..... | + .018 |
| .40 | .752 | .600 | .722 | .742 | 0.93 | ..... | + .004 |
| .41 | .771 | .630 | .745 | .745 | 0.84 | ..... | |
| .42 | .789 | .655 | .764 | .748 | 0.80 | ..... | + .001 |
| .43 | .804 | .678 | .780 | .751 | 0.81 | ..... | .000 |
| .44 | .819 | .700 | .792 | .754 | 0.92 | ..... | |
| .45 | .832 | .719 | .801 | .757 | 0.97 | ..... | − .004 |
| .46 | .838 | .732 | .810 | .760 | 0.95 | ..... | |
| .47 | .847 | .745 | .817 | .763 | 0.89 | ..... | |
| .48 | .854 | .758 | .823 | .766 | 0.75 | 6 | |
| .49 | .861 | .768 | .828 | .770 | 0.55 | 16 | |
| .50 | .869 | .778 | .833 | .773 | 0.32 | 79 | − .021 |
| .51 | .874 | .783 | .838 | .776 | 0.16 | 215 | |
| .52 | .879 | .788 | .843 | .778 | 0.07 | 292 | |
| .53 | .883 | .792 | .848 | .780 | 0.03 | 340 | |
| .54 | .887 | .797 | .852 | .782 | 0.01 | 386 | |
| .55 | .882 | .803 | .856 | .783 | ..... | 422 | − .042 |
| .56 | .895 | .809 | .860 | .785 | ..... | 415 | |
| .57 | .900 | .818 | .864 | .787 | ..... | 338 | |
| .58 | .904 | .827 | .868 | .789 | ..... | 105 | |
| .59 | .908 | .837 | .872 | .791 | ..... | 7 | |
| .60 | .911 | .847 | .876 | .792 | ..... | ..... | − .035 |
| 0.70 | 0.943 | 0.900 | 0.902 | 0.757 | ..... | ..... | −0.027 |

* Edison Pettit, *Mt. W. Contr.*, No. 622; *Ap. J.*, **91**, 159, 1940.

† Edison Pettit, *Pub. A.S.P.*, **46**, 27, 1934.

‡ See n. 12.

*c*) Observations of NPS stars with the Mount Wilson 60-inch telescope, two reflections from aluminized mirrors (subscript *a*); and a few, of magnitudes alone, with the Madison refractor.[11] The observed results are:

$$\left.\begin{aligned} &\text{Mount Wilson:}\quad \mathrm{Pe}_{wa}\,, \qquad C_2 = \mathrm{Pe}_{2\mathrm{B}wa} - \mathrm{Pe}_{2\mathrm{Y}wa}\,, \\ &\text{Madison:}\quad \mathrm{Pe}_{mr}\,. \end{aligned}\right\} \tag{11}$$

The $C_2$ of equation (11) can be distinguished from that of (10) by adding subscripts *a* and *s*, if the difference is not otherwise clear. For calculated values $w$ must be replaced

[11] Stebbins and Whitford, *Mt. W. Contr.*, No. 586; *Ap. J.*, **87**, 237, 1938, esp. Table 7.

by $m$, and $r$ by $r'$. The sensitivity factors are those of the preceding paragraph with the reflection coefficients of aluminum (Table 2, fifth column) substituted for those of silver.

The relations between color and spectral type for the three systems $C$, $C_1$, and $C_2$ are given in Table 9 and discussed in detail in section vii.

*Sensitivity-curves of photographic plates.*—No sensitivity measurements of either the Seed 27 or the Cramer Iso plate are available. Considerable information has been obtained, however, from a few grating spectrograms of northern skylight, taken on Mount Wilson in 1913 with a small plate-testing spectrograph. The Iso plate was exposed behind the standard yellow filter used for Pv observations.

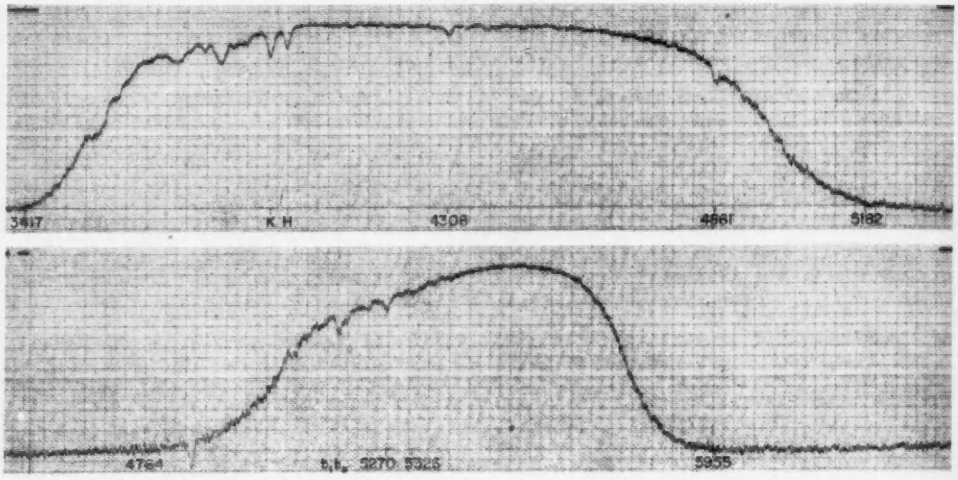


FIG. 1.—Spectral regions comprised in photographic and photovisual magnitudes. Microphotometer tracings of small-scale, transmission-grating spectrograms; exposures to northern skylight on Mount Wilson. Scale of reproduction, 1 mm = 15.6 A. *Above*, Seed 27 plate (Pg *m*); *below*, Cramer Instantaneous Iso exposed behind yellow filter *C* (Pv *m*). Since the glass parts of the spectrograph are thin, the absorption losses are nearly the same as the reflection losses from two silvered mirrors. Hence the regions illustrated correspond closely to those of the international system.

Figure 1 illustrates microphotometer tracings for a pair of these spectrograms, covering approximately the intervals λλ 3420–5170 and λλ 4900–5900. The average weighted mean wave lengths of the density-curves were found to be

$$\lambda_{27s} = 4270\,\text{A}\,, \qquad \lambda_{is} = 5430\,\text{A}\,. \tag{12}$$

The densities are normal and for the most part must lie on the straight portion of the characteristic curve. Moreover, the lenses of the spectrograph were thin and the absorption light. Hence the values (12) are probably nearly the same as those defined by equations (4) for the unknown equivalent temperature of the source—sunlight plus much scattered light—which later is found to be about 9000°. The interval $\lambda_{is} - \lambda_{27s}$ and the range in λ for the Pv density-curve will later be useful in finding $\lambda_e$ for the Pv standards.

It is an important fact that exposures made with the Eastman 40 plate show no color equation relative to the international Pg system; a coefficient as large as 0.03 could scarcely have escaped attention. For this plate, however, we have a sensitivity-curve,[12] the values of $s$ being inversely as the energies required to produce a photographic density

[12] C. E. K. Mees, *Jour. Opt. Soc. Amer.*, **21**, 767, 1931. Ordinates derived from Mees's diagram are in Table 2, col. (6).

of 0.8 for a development to standard contrast. For the present we accept these laboratory conditions as representing approximately the average conditions at the telescope—a detail to be justified later. The calculated wave lengths and magnitudes for the Eastman 40 plate are denoted by the symbols $\lambda_{40}$ and $Pg_{40}$, with a subscript $s$ (silvered mirrors) sometimes added.

### III. COMPUTED WAVE LENGTHS, COLORS, ETC.

The computed relations, of course, refer to the idealized conditions of black-body radiation. A detail more easily overlooked is that they also refer to freshly deposited silver or aluminum. The effect of tarnish on silvered mirrors is taken into account later.

*Results for silvered mirrors.*—The top and middle sections of Table 3 give results for the $C_1$ and $C_2$ systems of Stebbins (divisions [*a*] and [*b*] of sec. ii) computed by equations (4) and (6), and (3) or (7) of section i. Since all photoelectric observations refer to zero air mass, atmospheric extinction has not been included in the values of $s$. As already noted, the symbols for the tabular results are those of formulae (9) and (10) with $r'$ and $m$ replacing $r$ and $w$.

The differences between the two series of $\lambda_{Pe}$, column (3), arise wholly from the differential effect between the absorption, $r'$, for the Madison refractor and the reflection losses for the Mount Wilson silvered mirrors. The corresponding differences in the computed Pe's (col. [8], bottom section of Table 3), which have the form $Pe_{ms} - Pe_{mr'}$, define the relative color equation. Comparison with the corresponding observed values, $Pe_{ws} - Pe_{mr}$, if such were available, would help to determine the difference between the photocells and the error in $r'$, the approximation for $r$.

The bottom section of Table 3 gives, first, effective wave lengths for the Eastman 40 plate, which provisionally is accepted as the equivalent of the Seed 27. The sensitivity factors for the plate, the reflection coefficients for silver, and the atmospheric transmission at the pole are in Table 2. Multiplied together, they give the sensitivity factors required to find $\lambda_{40s}$ and $k_{40s}$ from equations (4) and (6).

Since we have no sensitivity-curve for the Iso plate, the values of $\lambda_{Pv} = \lambda_{is}$ must be found from the density-curve for the plate and the mean wave lengths for the skylight spectrograms (formulae [12]). Two steps are involved: first, the zero point for $\lambda_{Pv}$, and, second, the range in the $\lambda$'s. Since $\lambda_{27}$ and $\lambda_{40}$ are certainly nearly the same, comparison of the first of (12) with the values of $\lambda_{40}$ in Table 3 indicates for the skylight source an equivalent temperature of 9000°. Hence we infer that $\lambda_{Pv} = 5430$ also refers to 9000°, a value adopted as fixing the zero point.

Next, to find the range in $\lambda_{Pv}$, we use the ordinates of the mean density-curve for several of the Iso spectrograms (col. [7], Table 2; units arbitrary) as sensitivity factors for substitution into the second of formulae (4). The effective wave lengths thus found for the temperature sequence 22,000°–3,000° range over an interval of 60 A. For 9000°, $\lambda_e = 5411$. Hence a correction of +19 A is required to reduce the series to the adopted zero point. The resulting values for $\lambda_{Pv}$, and those of log $k_{Pv}$ which remain unchanged, are in columns (5) and (6), bottom section of Table 3. Finally, the theoretical color indices $C_s = Pg_{40s} - Pv_{is}$ are shown in column (7).[13]

The justification of the method used to find $\lambda_{Pv}$ lies in the fact that the shape of the sensitivity-curve has little influence on the range in the effective wave lengths; the interval covered by the curve is far more important. The interval, however, is well determined by the mean density-curve of the Iso spectrograms. As a test, the pronounced asymmetry of this curve was removed by averaging its ordinates—first and last, second

[13] Dr. Walter Baade has called our attention to the fact that the relationship between the theoretical values of $\lambda_{40s}$ and $C_s$ in Table 3 is almost identical with that between the observed colors of polar stars and their effective wave lengths as measured by E. Hertzsprung and by H. Vanderlinden. The matter will be discussed in a later *Contribution*.

## TABLE 3

### EFFECTIVE WAVE LENGTHS AND THEORETICAL COLOR INDICES

| $T$* (1) | $c_2/T$ (2) | $\lambda_{Pe}$ (3) | log $k_{Pe}$† (4) | $\lambda_B$ (5) | log $k_B$ (6) | $\lambda_Y$ (7) | log $k_Y$ (8) | $C_{BY}$ (9) |
|---|---|---|---|---|---|---|---|---|
| | Stebbins $C_1$ System ($mr'$, 0 air mass) | | | | | | | |
| ∞ | 0.00 | ..... | ..... | ..... | ..... | ..... | ..... | −0.29 |
| 30 | 0.48 | 4411 | ..... | 4202 | ..... | 4702 | ..... | − .185 |
| 22 | 0.65 | 4419 | − 41 | 4208 | − 30 | 4708 | − 27 | − .143 |
| 17 | 0.84 | 4427 | − 27 | 4215 | − 17 | 4714 | − 16 | − .104 |
| 13.7 | 1.05 | 4436 | − 11 | 4222 | − 9 | 4722 | − 8 | − .059 |
| 11 | 1.30 | 4448 | 0 | 4230 | 0 | 4730 | 0 | .000 |
| 9 | 1.59 | 4463 | + 8 | 4240 | + 4 | 4741 | + 7 | + .072 |
| 7 | 2.05 | 4487 | + 3 | 4254 | − 4 | 4760 | + 7 | + .187 |
| 6 | 2.39 | 4505 | − 16 | 4266 | − 18 | 4774 | − 2 | + .276 |
| 5 | 2.87 | 4531 | − 63 | 4282 | − 50 | 4794 | − 31 | + .402 |
| 4 | 3.58 | 4570 | −181 | 4301 | −120 | 4825 | −107 | + .595 |
| 3.5 | 4.09 | 4599 | −301 | 4320 | −207 | 4848 | −188 | + .733 |
| 3 | 4.78 | 4639 | −513 | 4339 | −329 | 4878 | −327 | +0.919 |
| | Stebbins $C_2$ System ($ms$, 0 air mass) | | | | | | | |
| ∞ | 0.00 | ..... | ..... | ..... | ..... | ..... | ..... | −0.20 |
| 30 | 0.48 | 4376 | ..... | 4278 | ..... | 4618 | ..... | − .128 |
| 22 | 0.65 | 4388 | − 42 | 4283 | − 32 | 4621 | − 24 | − .098 |
| 17 | 0.84 | 4398 | − 29 | 4290 | − 24 | 4625 | − 20 | − .073 |
| 13.7 | 1.05 | 4408 | − 15 | 4298 | − 8 | 4630 | − 5 | − .040 |
| 11 | 1.30 | 4424 | 0 | 4308 | 0 | 4636 | 0 | .000 |
| 9 | 1.59 | 4440 | + 4 | 4319 | + 7 | 4645 | + 7 | + .048 |
| 7 | 2.05 | 4466 | + 2 | 4337 | 0 | 4660 | + 3 | + .123 |
| 6 | 2.39 | 4487 | − 18 | 4350 | − 16 | 4672 | − 5 | + .182 |
| 5 | 2.87 | 4516 | − 66 | 4368 | − 54 | 4690 | − 32 | + .262 |
| 4 | 3.58 | 4559 | −195 | 4394 | −138 | 4717 | −105 | + .384 |
| 3.5 | 4.09 | 4587 | −320 | 4411 | −220 | 4740 | −192 | + .470 |
| 3 | 4.78 | 4629 | −539 | 4433 | −348 | 4769 | −334 | +0.585 |

| $T$ | $c_2/T$ | INTERNATIONAL SYSTEM‡ | | | | | $Pe_{ms} - Pe_{mr'}$ | $C - 2.97C_2$ |
|---|---|---|---|---|---|---|---|---|
| | | $\lambda_{40s}$ | log $k_{40s}$ | $\lambda_{Pvs}$ | log $k_{Pvs}$ | $C_s$ | | |
| ∞ | 0.00 | ..... | ..... | ..... | ..... | −0.63 | ..... | −0.03 |
| 30 | 0.48 | 4163 | ..... | 5415 | ..... | −0.400 | −0.013 | − .020 |
| 22 | 0.65 | 4182 | − 91 | 5418 | −13 | −0.314 | − .010 | − .023 |
| 17 | 0.84 | 4198 | − 52 | 5420 | −10 | −0.224 | − .007 | − .007 |
| 13.7 | 1.05 | 4216 | − 28 | 5423 | − 4 | −0.127 | − .005 | − .008 |
| 11 | 1.30 | 4242 | 0 | 5426 | 0 | 0.000 | .000 | .000 |
| 9 | 1.59 | 4272 | + 12 | 5430 | + 1 | +0.152 | + .004 | + .009 |
| 7 | 2.05 | 4318 | − 9 | 5437 | + 4 | +0.386 | + .010 | + .021 |
| 6 | 2.39 | 4351 | − 50 | 5442 | + 4 | +0.561 | + .013 | + .020 |
| 5 | 2.87 | 4398 | −146 | 5449 | + 1 | +0.800 | + .017 | + .022 |
| 4 | 3.58 | 4465 | −359 | 5460 | −21 | +1.141 | + .022 | .000 |
| 3.5 | 4.09 | 4508 | −551 | 5468 | −38 | +1.371 | + .027 | − .025 |
| 3 | 4.78 | 4559 | −830 | 5478 | −70 | +1.660 | +0.031 | −0.078 |

* Unit, 1000°. † Unit, 0.0001.

‡ Silvered mirrors; values include the effect of differential atmospheric extinction (stellar temperature effect) at the pole.

and last but one, etc. On repeating the calculation, the range in $\lambda_e$ was increased to 71 A; the values of $C$, however, were practically identical with those in Table 3, the largest difference being 0.005 mag. The chief uncertainty in $\lambda_{Pv}$ is, therefore, in the zero point, for which the estimated mean error is 20 A.

Frequently it is necessary to suppose that linear relations connect different color systems. The departures from such a relation, namely, $C = 2.97C_2$, are shown in the last column at the bottom of Table 3. The similar differences for the relation $C = 1.92C_1$ are even larger. Usually such deviations are lost in the errors of observation.

*Aluminized mirrors.*—The changes in Table 3 produced by substituting aluminum for silver are given in Table 4—columns (3)–(6) for the international system, (7)–(10) for the Mount Wilson photoelectric results. The change in $\lambda_{Pv}$ is negligible and that in Pv itself—a loss of 0.094 mag.—is practically independent of temperature. Pg, on the other hand (col. [5]), shows for 22,000° a gain of 0.166 and for 3000° a loss of 0.037 mag. The

TABLE 4

RESULTS FOR ALUMINIZED MIRRORS

| $T$ (1) | $c_2/T$ (2) | $\lambda_{40a}$* (3) | log $k_{40a}$ (4) | $Pg_{40a} - Pg_{40s}$† (5) | $C_a - C_s$ (6) | $\lambda_{Pea}$ (7) | log $k_{Pea}$ (8) | $Pe_{ma} - Pe_{ms}$ (9) | $C_{2a} - C_{2s}$ (10) |
|---|---|---|---|---|---|---|---|---|---|
| 30..... | 0.48 | 4010 | ..... | ..... | ..... | ..... | ..... | −0.026 | |
| 22..... | 0.65 | 4035 | − 119 | −0.166 | −0.051 | 4315 | − 67 | − .019 | −0.008 |
| 17..... | 0.84 | 4060 | − 68 | − .152 | − .037 | 4330 | − 42 | − .012 | − .005 |
| 13.7... | 1.05 | 4086 | − 33 | − .134 | − .019 | 4349 | − 18 | − .004 | − .004 |
| 11..... | 1.30 | 4122 | 0 | − .114 | .000 | 4375 | 0 | + .007 | .000 |
| 9..... | 1.59 | 4164 | + 13 | − .092 | + .022 | 4398 | + 8 | + .016 | + .003 |
| 7..... | 2.05 | 4228 | − 21 | − .061 | + .053 | 4433 | − 2 | + .028 | + .007 |
| 6..... | 2.39 | 4273 | − 81 | − .041 | + .073 | 4457 | − 19 | + .034 | + .011 |
| 5..... | 2.87 | 4334 | − 212 | − .018 | + .096 | 4491 | − 80 | + .041 | + .017 |
| 4..... | 3.58 | 4418 | − 491 | + .009 | + .123 | 4539 | −228 | + .052 | + .020 |
| 3.5... | 4.09 | 4472 | − 727 | + .017 | + .130 | 4571 | −367 | + .057 | + .025 |
| 3..... | 4.78 | 4533 | −1076 | +0.037 | +0.150 | 4619 | −614 | +0.062 | +0.028 |

* The Pv effective wave length for aluminized mirrors is sensibly the same as for silver, column (5), bottom section Table 3; for hot stars, $\lambda_{Pva} - \lambda_{Pvs} = -1$ A, for cool ones −2 A.

† The corresponding Pv difference is $Pv_a - Pv_s = +0.094 \pm 0.001$ mag. for all temperatures.

colors $C_a$ are found by adding the differences in column (6), Table 4, to the values of $C_s$ in Table 3. The computed results for Pg, Pv, and $C$, like those in Table 3, include the influence of differential extinction (temperature effect) at the pole.[14]

The changes in the photoelectric data are smaller; but that in Pe (col. [9], Table 4) should be within observational reach. Any comparison of computed with observed differences for silver and aluminum mirror surfaces is likely, however, to reveal discordances. Neglected line absorption and other departures of the stellar radiation from that of a black body, as well as uncertain reflection losses, especially in the silver film, will always complicate the results.

The $k$'s of Tables 3 and 4 deserve a word of comment. Their values follow curves which have a family relationship such that with some additional data it should be possible to pass from one to another when only one or two of the larger values of $k$ are known. Further, when the values for a specific temperature are studied, it is found that they bear simple relations to the values of $\lambda_e$ for that temperature and to the ranges in $\lambda_e$. These properties are useful in intercomparing magnitude systems, for some of which sensitivity factors may be lacking and the direct calculation of $k$ impossible.

[14] Similar values, which include the extinction at the zenith, have been given by Edison Pettit, *Pub. A.S.P.*, **46**, 27, 1934.

## IV. INFLUENCE OF ATMOSPHERIC EXTINCTION

Extinctions at the pole and at the zenith have been calculated for the various magnitudes for each of the standard temperatures. The general formula, an adaptation of equation (2), is

$$\text{Ext.} = -2.5 \log \frac{\Sigma \tau s y}{\Sigma s y}, \qquad (13)$$

where $\tau$ is the transmission coefficient for the wave length $\lambda$ corresponding to $sy$ at the pole or at the zenith (Table 2) as required, and $s$ includes the other elements of the sensitivity factor. Heretofore, $\tau$, when used, has been included in $s$. The results, expressed in magnitudes, are given in Tables 5 and 6.[15]

TABLE 5

ATMOSPHERIC EXTINCTION

| $T$ | $c_2/T$ | $Pg_{40a}$ | | | $Pg_{40a}-Pv$ | | $Pe_{ma}$ | | | O−C‡ FROM $\lambda^{-4}$ LAW |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $\Delta\lambda$* | Ext.† NP | Ext.† Zen. | $\Delta C_{NP}$ | $\Delta C_{Zen}$ | $\Delta\lambda$ | Ext. Zen. | $\Delta$Ext. NP | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) | (10) | (11) |
| 30..... | 0.48 | ..... | ..... | ..... | −0.041 | −0.023 | ..... | ..... | ..... | |
| 22..... | 0.65 | −94A | −0.560 | −0.313 | − .033 | − .018 | −24A | −0.263 | −0.016 | −0.009 |
| 17..... | 0.84 | 92 | .552 | .309 | − .025 | − .014 | 23 | .261 | − .013 | |
| 13.7.... | 1.03 | 90 | .541 | .302 | − .014 | − .008 | 23 | .258 | − .007 | − .007 |
| 11..... | 1.30 | 90 | .527 | .295 | .000 | .000 | 21 | .254 | .000 | |
| 9..... | 1.59 | 86 | .514 | .287 | + .013 | + .007 | 20 | .250 | + .007 | − .002 |
| 7..... | 2.05 | 81 | .491 | .274 | + .035 | + .020 | 19 | .246 | + .014 | .000 |
| 6..... | 2.39 | 75 | .474 | .265 | + .051 | + .029 | 18 | .244 | + .020 | |
| 5..... | 2.87 | 69 | .452 | .253 | + .073 | + .041 | 17 | .239 | + .027 | + .003 |
| 4..... | 3.58 | 60 | .424 | .237 | + .100 | + .056 | 16 | .233 | + .038 | + .006 |
| 3.5.... | 4.09 | 54 | .406 | .227 | + .118 | + .066 | 15 | .229 | + .045 | |
| 3..... | 4.78 | −46 | −0.386 | −0.216 | +0.137 | +0.077 | −15 | −0.224 | +0.054 | +0.007 |

* Corrections to $\lambda_{40a}$, Table 3, which remove effects of extinction at the pole, that is, reduce the Pg effective wave lengths to zero air mass. For Pv the corresponding $\Delta\lambda$ is $-3 \pm 1$ A. The reduction from the pole to the zenith is $0.44\Delta\lambda$, and for Pg thus ranges from −41 to −20 A for the temperature interval 22,000°–3000°.

† Corrections to $Pg_{40a}$, which completely remove extinction affecting observations made at the pole and at the zenith. For Pv the correction at the pole changes from −0.244 at 22,000° to −0.240 at 3000°. At the zenith it is practically constant, $-0.135 \pm 0.001$ for this same interval.

‡ Integrated extinctions compared with values from effective wave lengths and Rayleigh's law. The same formula and constant give for the photovisual region O − C = −0.01 mag.

Actually, the values of the Pg zenith extinction in column (5), Table 5, were found not from equation (13) but from the polar values in column (4) by applying the air-mass factor 1/1.79. The differences between these two columns—the Pg reductions from pole to zenith—were then independently calculated by equation (13). The agreement, everywhere within 0.002 mag., checks the numerical accuracy of the results. As explained in the notes to Table 5, the Pv extinctions are practically independent of stellar temperature. The differential effect of temperature on the color index (cols. [6] and [7], Table 5) is therefore the same as that on the Pg magnitude. This effect, which heretofore has always been neglected in photometric work, is to be regarded as an error in the observed data now under discussion.

[15] The best mean zenith extinctions for Mount Wilson hitherto available are Pg, 0.295 and Pv, 0.128 mag. (*Mt. W. Cat. of Selected Areas*, p. xxxvi, 1930). Since the corresponding equivalent mean temperature now appears to have been about 9000°, the agreement with Table 5 is satisfactory.

Since the NPS standards have already been reduced to the zenith (approximately) by the application of mean extinctions, the correction formulae are

$$\left.\begin{aligned} \text{Pg}m\ (\text{zenith}) &= \text{Pg}m + \text{col.}\ (6) - \text{col.}\ (7)\ , \\ \text{Pv}m\ (\text{zenith}) &= \text{Pv}m\ , \end{aligned}\right\} \qquad (13a)$$

$$\left.\begin{aligned} \text{Pg}m\ (0\ \text{air mass}) &= \text{Pg}m + \text{col.}\ (6) - 0.295\ , \\ \text{Pv}m\ (0\ \text{air mass}) &= \text{Pv}m - 0.136\ , \end{aligned}\right\} \qquad (13b)$$

in which the column numbers refer to Table 5. The constants, 0.295 and 0.136 mag., are the Pg and the Pv zenith extinctions for $T = 11{,}000°$; they agree closely enough with the mean values used for the original reduction of the standards to the zenith.

The results in columns (4)–(7) in Table 5 show that the universal practice of using the same extinction for all spectral types often leads to serious errors. For an A0 and a

TABLE 6

EFFECT OF ZENITH EXTINCTION ON $C_1$ AND $C_2$

| $T$ | $C_1$* | | | $C_2$ | | |
|---|---|---|---|---|---|---|
| | 1B | 1Y | $\Delta C_1$ | 2B | 2Y | $\Delta C_2$ |
| 11,000° | +0.306 | +0.215 | −0.091 | +0.242 | +0.189 | −0.053 |
| 4,000 | +0.286 | +0.205 | −0.081 | +0.224 | +0.182 | −0.042 |

* Computed with Mount Wilson transmission coefficients and reduced to the elevation of Madison by applying the air-mass factor 1.19.

K0 star at the pole the differential effect on Pg (and $C$) is 0.12 mag. Observed at 60° zenith distance and reduced to the zenith by the same correction, the magnitudes of such stars would be affected by a relative error of 0.07 mag. If corrected accordingly, they would still include the influence of the unit air mass at the zenith—another 0.07 mag. For the extremes of temperature, say 22,000°–3000°, the error is even more serious. The quantities involved are much too large to be neglected; but allowance for them requires a temperature index of some kind, either color or spectral type, and for faint stars, at least, both these characteristics are usually lacking.

The effective wave lengths are, of course, also influenced by extinction. The corrections which reduce the values for international Pg magnitudes ($\lambda_{40s}$, Table 3) to zero air mass are in column (3), Table 5. The reduction to the zenith (note to table) follows the air-mass relations (0.79/1.79), as was confirmed by a direct calculation. Here again the differential temperature effect is not negligible. For example, in the reduction from pole to zenith, for the interval 11,000°–4000°, it amounts to 0.06 mag. in $C$. For $\lambda_{Pv}$ the reduction to zero air mass for polar stars is only −3 A, the same for all temperatures.

The zenith differential error in Pe (Mount Wilson observations) for the interval 11,000°–4000° is about 0.02 mag. (col. [9], Table 5); in $C_1$ and $C_2$, 0.01 mag. (Table 6). For other air masses there is a proportional increase, for example, to 0.038 at the pole for Pe (col. [10], Table 5).

The values of $C$ in Table 6 and of the corrections in column (9), Table 5, should be comparable with the observed values for the zenith used to reduce the photoelectric measurements to zero air mass. The agreement in the corrections for color, as far as

can be judged, is satisfactory.[9,10,16] The computed corrections for Pe, on the other hand, are systematically smaller than the zenith value, 0.30, used for reducing the observed Pe magnitudes to zero air mass.

## V. CORRECTIONS FOR SPACE ABSORPTION

The stars in the polar region, comprising a large part of the material under discussion, show an excess of color, which gradually increases to a maximum of 0.27 mag. at a distance (apparent) of 600 or 700 parsecs. The observations must be freed from this disturbance.

The observed color index of a star may be completely corrected for absorption by subtracting the color excess, $E$, an observed quantity found without any assumption as to the law of absorption. $E$ must depend on the effective wave length and hence. to some degree at least, on the temperature of the star; but to reveal this relationship to temperature would require an abundance of data not yet available. For this reason the values of $E$, found in *Mt. W. Contr.*, No. 684, are averages for all temperatures together. With effective wave lengths now available, corrections for temperature differences can be computed, if we are willing to commit ourselves to a specific form for the law of absorption.

Owing to the probable diversity in size and composition of the absorbing particles, no universal law is to be expected. Nevertheless, the current evidence indicates that the relation $A = \rho\lambda^{-1}$ ($A$, the absorption in magnitudes) is so often an excellent approximation as to justify its use for general discussions.

For the international system we have, accordingly,

$$E = A_{\mathrm{Pg}} - A_{\mathrm{Pv}} = \rho\,(\lambda_{\mathrm{Pg}}^{-1} - \lambda_{\mathrm{Pv}}^{-1})\,, \tag{14}$$

and for the important ratios of Pg and Pv absorptions to color excess,

$$R_{\mathrm{Pg}} = \frac{A_{\mathrm{Pg}}}{E} = \frac{\lambda_{\mathrm{Pg}}^{-1}}{\lambda_{\mathrm{Pg}}^{-1} - \lambda_{\mathrm{Pv}}^{-1}}\,, \qquad R_{\mathrm{Pv}} = R_{\mathrm{Pg}} - 1\,. \tag{15}$$

The combination of two such equations gives the effect of absorption on a magnitude difference. Thus for $\mathrm{Pg}_{27s} - \mathrm{Pe}_{wa}$ and $\mathrm{Pe}_{wa} - \mathrm{Pe}_{mr}$, requiring attention later,

$$A_{27s} - A_{wa} = E\,\frac{\lambda_{27s}^{-1} - \lambda_{wa}^{-1}}{\lambda_{27s}^{-1} - \lambda_{\mathrm{Pv}}^{-1}} = EF\,, \tag{16}$$

$$A_{wa} - A_{mr} = E\,\frac{\lambda_{wa}^{-1} - \lambda_{mr}^{-1}}{\lambda_{27s}^{-1} - \lambda_{\mathrm{Pv}}^{-1}} = EF_1\,. \tag{17}$$

Results from formulae (14)–(16) are given in Table 7. First, values of $E/\rho$, in arbitrary units, for the international system. These quantities represent the theoretical variation in $E$ with temperature. The mean color-excess curve for the polar stars corresponds to about 7000°, for which $E/\rho = 477$. The supplementary absorption correction for a star of another temperature, say 22,000°, is, then, $E\Delta E/477 = +0.147E$, where $E$ is the color excess from the mean curve for the distance in question and the coefficient +0.147 is from column (4), Table 7.

[16] Stebbins, Huffer, and Whitford, *Mt. W. Contr.*, No. 621; *Ap. J.*, **91**, 20, 1940. Note that, in comparing the result given in this citation with the values of $\Delta C_1$ in Table 6, the latter must be multiplied by 0.84 to reduce them to the Mount Wilson zenith air mass. To avoid possible confusion, it may be remarked that the $C_1$ observations of *Contribution* No. 621, which were made at Mount Wilson, do not enter into the present discussion.

The mean spectrum-color relationship given in Table 7, *Mt. W. Contr.*, No. 684 (already corrected for mean color excess), has been revised in this manner. The temperatures corresponding to different spectral types required for the calculation are given with sufficient accuracy by columns (1) and (7), bottom section of Table 3. The resulting corrections to the mean color indices, $C$, appear in column (4), Table 9. Allowance for the differential temperature effect on $E$ thus increases the range in $C$ by about 0.06 mag. $C_1$ and $C_2$, based on stars in unobscured regions, presumably require no such correction.

The quantities $F$ and $F_1$ (cols. [5] and [6], Table 7) are factors appearing in equations (16) and (17). In computing them we use $\lambda_{40s}$ for $\lambda_{27s}$ as usual; $\lambda_{wa}$ must be replaced by $\lambda_{ma}$ (col. [7], Table 4), and $\lambda_{mr}$ by $\lambda_{mr'}$ given in column (3), top section of Table 3. Since the corrections are all very small, none of these substitutions is of any consequence.

TABLE 7

FACTORS RELATING TO SPACE ABSORPTION, $\lambda^{-1}$ LAW

| $T$ (1) | $c_2/T$ (2) | $E/\rho$ (3) | $\Delta E/477$ (4) | $F$ (5) | $F_1$ (6) | $A_{Pg}/E$* (7) | $A_{Pg}/E_1$† (8) | $A_{Pg}/E_2$‡ (9) | $A_{Pv}/A_{Pg}$§ (10) |
|---|---|---|---|---|---|---|---|---|---|
| 22 | 0.65 | 547 | +0.147 | +0.14 | +0.10 | 4.4 | 9.5 | 14.0 | 0.77 |
| 17 | 0.84 | 538 | + .128 | .14 | .09 | 4.4 | 9.5 | 14.1 | .77 |
| 13.7 | 1.05 | 528 | + .107 | .14 | .09 | 4.5 | 9.4 | 14.2 | .78 |
| 11 | 1.30 | 514 | + .078 | .14 | .08 | 4.6 | 9.4 | 14.4 | .78 |
| 9 | 1.59 | 500 | + .048 | .13 | .07 | 4.7 | 9.4 | 14.5 | .79 |
| 7 | 2.05 | 477 | .000 | .13 | .06 | 4.9 | 9.3 | 14.5 | .79 |
| 6 | 2.39 | 461 | − .034 | .12 | .05 | 5.0 | 9.2 | 14.5 | .80 |
| 5 | 2.87 | 439 | − .080 | .11 | .05 | 5.2 | 9.1 | 14.5 | .81 |
| 4 | 3.58 | 408 | − .145 | .09 | .04 | 5.5 | 8.9 | 14.4 | .82 |
| 3.5 | 4.09 | 389 | − .184 | .08 | .03 | 5.7 | 8.8 | 14.1 | .82 |
| 3 | 4.78 | 368 | −0.228 | +0.08 | +0.02 | 6.0 | 8.6 | 13.8 | 0.83 |

* Ratio of total Pg absorption (exclusive of any nonselective absorption) to color excess; international system, including extinction at the pole. Change from silvered to aluminized mirrors reduces ratios to 3.9 for 22,000° and to 5.8 for 3000°.

† $E_1$ is the color excess for the Madison photoelectric observations (Stebbins and Huffer).

‡ $E_2$, photoelectric observations by Stebbins and Whitford, at Mount Wilson, with silvered mirrors. Change to aluminum surfaces gives 13.5 for 22,000° and 3000°, with a maximum of 14.1 for 7000°.

§ Factors for obtaining $A_{Pv}$, international system, from ratios in cols. (7)–(9). From the first of these ratios, more directly, $A_{Pv}E^{-1} = A_{Pg}E^{-1} - 1$.

Columns (7)–(9), Table 7, give the important ratios in formula (15), required for converting observed color excess into total photographic absorption on the international scale. The last column shows factors for finding the total photovisual absorption. These totals are exclusive of any nonselective absorption that may be present. Details are explained in the notes to the table.

## VI. APPLICABILITY OF EFFECTIVE WAVE LENGTHS TO CALCULATIONS OF ABSORPTION

The foregoing calculations assume that the absorption, $A_e$, found from the relation $A = \rho\lambda^{-1}$ with the effective wave length $\lambda_e$ is equal to $A_\tau$ derived by integrating the losses over the entire range in $\lambda$. The latter result, from equation (13), is

$$A_\tau = -2.5 \log \frac{\Sigma \tau s y}{\Sigma s y} = -2.5 \log \bar{\tau}\,, \qquad (18)$$

where $\tau = 10^{-0.4A}$ is the space-transmission coefficient corresponding to the $\lambda$ involved in $sy$. The equivalence of $A_e$ and $A_\tau$ is not obvious and, analytically at least, is not exact. We have the equalities

$$\frac{\rho}{A_e} = \lambda_e = \frac{\Sigma \lambda\, sy}{\Sigma\, sy} = \rho \frac{\Sigma \frac{1}{A}\, sy}{\Sigma\, sy} = \rho \left(\overline{\frac{1}{A}}\right) = -0.4\,\rho \left(\overline{\frac{1}{\log \tau}}\right), \tag{19}$$

in which the second and third members are only the definition of $\lambda_e$ (eq. [4]).

The condition for equality of $A_e$ and $A_\tau$ is, therefore,

$$\left(\overline{\frac{1}{\log \tau}}\right) = \frac{1}{\log \bar{\tau}}, \tag{20}$$

a relation which is not satisfied, since it takes no account of the distribution function for $1/\log \tau$ and $\tau$. The matter is further complicated by the fact that this function, which is expressed numerically by the sequence of weighting factors $sy$, changes with the temperature of the star.

TABLE 8

ABSORPTION FROM $\lambda_e$ COMPARED WITH INTEGRATED ABSORPTION, $\lambda^{-1}$ LAW

| | PHOTOGRAPHIC | | | PHOTOVISUAL | | |
|---|---|---|---|---|---|---|
| | 3000° | 7000° | 22,000° | 3000° | 7000° | 22,000° |
| $\lambda_e$ | 4559A Mag. | 4318A Mag. | 4178A Mag. | 5478A Mag. | 5437A Mag. | 5418A Mag. |
| $A_e$ | 0.947 | 1.000 | 1.034 | | | |
| $A_\tau - A_e$ | +0.001 | +0.006 | +0.005 | | | |
| $A_e$ | 1.894 | 2.000 | 2.067 | | | |
| $A_\tau - A_e$ | +0.002 | +0.005 | 0.000 | | | |
| $A_e$ | 4.736 | 5.000 | 5.168 | 4.962 | 5.000 | 5.017 |
| $A_\tau - A_e$ | −0.035 | −0.062 | −0.080 | −0.013 | −0.014 | −0.014 |

The correctness of the values of $A_e$ can be tested only by calculation. Table 8 gives results for three values of the Pg absorption, each computed for temperatures of 3000°, 7000°, and 22,000°. The comparisons are conclusive because the sensitivity-curve of the Eastman 40 plate covers the longest wave-length interval with which we are concerned, about 2000 A.

The starting-point for each comparison was an assumed value of $A_e$ for 7000°: 1, 2, and 5 mag., respectively, which fixed the value of $\rho$. Thus for $A_e = 1$ mag., $\rho = 4318$. The transmission coefficient was then computed from $\log \tau = -0.4 \times 4318\lambda^{-1}$ for each $\lambda$ (100-A intervals) required for the summation in (18). For absorptions of 1 and 2 mag. the differences $A_\tau - A_e$ scarcely exceed the error of calculation; for 5 mag. they amount to only a few hundredths.

Much larger differences might well have been expected. For $A_e = 5.00$ at $\lambda$4318, $\tau = 0.010$. Were the transmission coefficients the same for all wave lengths, $A_e$ would exactly equal $A_\tau$. Actually $\tau$ ranges as follows:

$$\begin{array}{llll} \lambda = 3300\,, & 4318\,, & 5500\,, \\ \tau = 0.002\,, & 0.010\,, & 0.027\,; \end{array}$$

and yet the defect in $\Sigma \tau sy$ for $\tau < 0.010$ so nearly neutralizes the excess for $\tau > 0.010$ that the total sum differs less than 6 per cent from the corresponding sum for $\tau = 0.010$ throughout.

For Pv absorptions the agreement should be even better because of the shorter range in λ—only 1000 A; and, in fact, it is, as shown by the differences in Table 8.

The only remaining detail is the effect on the ratio $A_{Pg}/E$. Computed for $A_e = 5$ mag. at 7000°, the ratio based on $\lambda_e$ is 4.86 (rounded off to 4.9 in Table 7), that from the summation process 5.03. Since values of $E$ larger than 1 mag. are rarely observed, it appears that absorptions calculated from the effective wave lengths defined by equation (4) are adequate in practice. For another law of absorption, however, the result might be different.

Rayleigh scattering, if large in amount, might be expected to cause difficulty. Although not the dominant type of absorption occurring in space, it plays an important part in terrestrial atmospheric extinction. With allowance for ozone absorption, Pettit,[17] for example, finds that on days of high transparency it accounts well for the atmospheric losses observed on Mount Wilson.

The transmission coefficients $\tau$ computed from

$$\frac{\log \tau}{\log \tau_0} = \frac{A}{A_0} = G\left(\frac{\lambda_0}{\lambda}\right)^4, \qquad G = \left(\frac{\mu - 1}{\mu_0 - 1}\right)^2 \tag{21}$$

give the differences O − C shown in the last column of Table 2. Values of log $G$, depending on the index of refraction of air,[18] run as follows (unit = 0.0001):

| λ.... | 3000 | 3500 | 4000 | 4237 | 4500 | 5000 | 5500 | 6000 | 7000 |
|---|---|---|---|---|---|---|---|---|---|
| log $G$.... | +308 | +136 | +34 | 0 | −30 | −75 | −108 | −133 | −165 |

The residuals of Table 2 show the strong influence of ozone in the ultraviolet. From λ 3300 to λ 4500 they are slightly systematic, but within the errors of measurement. From λ 4500 toward the red they suggest the influence of the broad shallow Chappûis bands of ozone, which extend to about λ 6500, with a maximum near λ 6100. Something more, however, is probably involved, for, if the differences are attributed wholly to ozone, the equivalent thickness of the ozone layer at N.P.T. would be of the order of 6 mm,[19] whereas Pettit[17] found from the ultraviolet bands, observed at the same time, only 1 mm. Moreover, the residual at λ 7000, beyond the ozone limit, is still large. The region includes many faint water-vapor lines; but it is not possible at present to distinguish between neglected absorption, observational error, and departures from Rayleigh's law. The uncertainty, however, does not affect the conclusion as to the applicability of effective wave lengths to the calculations.

Starting with an observed $\tau$ to determine the constant, we have found from Rayleigh's law transmission coefficients in good general agreement with the observed series. We may also start with an observed absorption and an effective wave length; for example, the photographic extinction at the pole for 7000° (col. [4], Table 5), namely, $A_\tau = A_0 = 0.491$ mag., an "observed" value in the sense that it has been computed from observed values of $\tau$. The equivalent $\tau_0$ from $\log \tau_0 = -0.4\, A_\tau$ is 0.636, a weighted mean, as shown by formula (18), corresponding, by assumption for the moment, to $\lambda_0 = \lambda_e = 4237$ (col. [3], Table 5; note that $\lambda_e$ for the unscattered radiation, not that in Table 3, is used). Substituted into equation (21), $\tau_0$ and $\lambda_e$ determine values of $\tau$ for the entire range in λ (100-A intervals). Summation by (18) then gives $A'_\tau = 0.530$, whence O − C = −0.039. A second approximation, beginning with $A_0 = 0.491 - 0.039$, gives revised transmission coefficients, which in turn lead to $A''_\tau = 0.490$, in agreement with the initial $A_\tau$.

[17] *Mt. W. Contr.*, No. 622, Fig. 4; *Ap. J.*, **91**, 159, 1940.

[18] *Smithsonian Physical Tables*, 8th ed., Table 413, 1932.

[19] Based on G. Colange's absorption coefficients (*J. phys.*, 6th ser., **8**, 254, 1927). For much detailed information and a valuable bibliography see J. Gauzit, *Étude de l'ozone atmosphérique par spectroscopie visuelle*, thesis, University of Paris, 1935.

With allowance for the difference in air mass, the deviations of the revised $\tau$'s from the observed values are essentially the same as the residuals for the zenith given in Table 2, that is, they agree with the values computed directly from equation (21).

Using $A_0 = 0.491$, $\lambda_0 = 4237$, as before, we now substitute into (21), in succession, other values of $\lambda_e$ (Table 5) to obtain values of $A_e$ for other temperatures. The deviations of these results from the values of $A_\tau$ (col. [4], Table 5) are in the last column of Table 5. Finally, substituting effective wave lengths for the photovisual region, we find, still with the same $A_0$ and $\lambda_0$, $A_{Pv} = 0.176$ mag. (nearly independent of temperature). This result differs considerably from the integrated value from the observed transmission coefficients (0.242, second note, Table 5) but agrees (O − C = −0.01) with the $A_\tau$ based on the computed coefficients of the preceding paragraph. The disagreement for the observed coefficients merely reflects the deviations of these coefficients from Rayleigh's law in the orange-red region. For moderate absorptions, at least, effective wave lengths can therefore be used in calculations involving Rayleigh scattering.

TABLE 9

COLOR INDEX AND SPECTRAL TYPE, GIANT STARS

| HD Sp (1) | $C$ | | | | | $C_1$ | | | | $C_2$ | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Obsd. (2) | δ Ext.NP (3) | δE (4) | 0 Air M* (5) | Zenith (6) | Obsd. (7) | Sp.† (8) | δExt.‡ (9) | 0 Air M (10) | Obsd. (11) | Sp.† (12) | δExt.‡ (13) | 0 Air M (14) |
| B5 | −0.39 | −0.036 | (−0.010) | −0.436 | −0.420 | −0.17 | −0.02 | −0.004 | −0.194 | −0.32 | +0.205 | −0.004 | −0.119 |
| A0 | −0.15 | − .018 | − .012 | −0.180 | −0.172 | − .10 | − .02 | − .002 | − .122 | − .27 | .205 | − .002 | − .067 |
| A2 | −0.05 | − .006 | − .010 | −0.066 | −0.063 | | | | | | | | |
| A5 | 0.00 | .000 | − .013 | −0.013 | −0.013 | + .03 | − .04 | .000 | − .010 | − .20 | .190 | .000 | − .010 |
| F0 | +0.12 | + .010 | − .005 | +0.125 | +0.121 | + .09 | − .03 | .000 | + .060 | − .16 | .205 | .000 | + .045 |
| F5 | +0.26 | + .022 | .000 | +0.282 | +0.272 | + .18 | − .04 | + .002 | + .142 | − .09 | .195 | + .002 | + .107 |
| G0 | +0.60 | + .055 | + .013 | +0.668 | +0.645 | + .33 | − .04 | + .005 | + .295 | − .01 | .195 | + .005 | + .190 |
| G5 | +0.78 | + .071 | + .019 | +0.870 | +0.839 | + .49 | − .04 | + .008 | + .458 | + .08 | .185 | + .008 | + .273 |
| G8 | +0.90 | + .080 | + .028 | +1.008 | +0.973 | | | | | | | | |
| K0 | +1.06 | + .094 | + .036 | +1.190 | +1.149 | + .64 | − .03 | + .010 | + .620 | + .17 | .225 | + .010 | + .405 |
| K2 | +1.25 | + .110 | +0.048 | +1.408 | +1.359 | | | | | | | | |
| K5 | +1.45 | +0.125 | | +1.623 | +1.568 | +0.90 | +0.03 | +0.014 | +0.944 | +0.30 | +0.285 | +0.014 | +0.599 |

* Strictly speaking, a zero-point correction of −0.159 mag. (determined by the difference between equations [13*b*]) is still required to obtain 0 air-mass values of $C$. Its neglect is of no consequence here, since $C$, $C_1$, and $C_2$ for A5 stars are all eventually made equal to zero for simplicity in interpolating $c_2/T$ from the temperature-color curves.

† Combined reduction to HD spectrum and zero-point correction, the latter −0.03 for $C_1$, +0.205 for $C_2$.

‡ These corrections, accidentally the same for $C_1$ and $C_2$, are for the zenith and hence too small, since the observations were not made at the zenith.

## VII. SPECTRUM AND COLOR INDEX

Before using the theoretical color indices in Table 3 to obtain color temperatures for different spectral types, the relationship of spectrum to color needs attention. The published data for giant stars given in columns (2), (7), and (11) of Table 9 are not directly comparable. The types for $C$ are on the HD system; those for $C_1$, on the system of the first Mount Wilson spectroscopic catalogue,[20] and those for $C_2$, on the later Mount Wilson catalogue.[21]

The photoelectric data are reduced to the HD system by modifying slightly the values of $C_1$ and $C_2$. For $C_2$ the corrections depend on the data of Table 2 (*Mt. W. Contr.*, No. 683). The stars used to obtain $C_1$ are listed in *Pub. Washburn Obs.*, **15,** Part V, Table VI. Revised classifications from *Mt. W. Contr.*, No. 511, may be used as a basis for correction, as was done for $C_2$, or the HD spectra may be used directly. By either method the results are sensibly the same.

Further, $C_1$ and $C_2$ require zero-point corrections such that the reduced colors for A5 will be −0.01, the same as the final value for $C$. The combined corrections for zero point and reduction to the HD system are in columns (8) and (12) of Table 9.

[20] Adams, Strömberg, and Burwell, *Mt. W. Contr.*, No. 199; *Ap. J.*, **53,** 13, 1921.

[21] Adams, Joy, Humason, and Brayton, *Mt. W. Contr.*, No. 511; *Ap. J.*, **81,** 187, 1935.

Next, all the colors require corrections for atmospheric extinction arising from differences in the temperatures of the stars—very small for $C_1$ and $C_2$, although worth applying because of the photoelectric precision, but important for $C$. In reducing $C_1$ and $C_2$ to zero air mass, stellar temperature differences were ignored, and $C$ and the Pg and Pv standards themselves, as already explained, have received no correction at all.

For $C_1$ and $C_2$ the required quantities, from the data in Table 6, are given in columns (9) and (13) of Table 9. The corresponding correction for $C$, from column (6), Table 5, which completely frees $C$ from the differential temperature effect, is in column (3) of Table 9. If $C$ is to be reduced to the zenith only, then use 0.559 of the values in column (3). Approximate temperatures found from observed colors and the temperature-color relations in Table 3 are sufficient for interpolations from Tables 5 and 6.

Finally, since $C_1$ and $C_2$ are from observations of stars in regions presumably free from obscuration, no allowance is to be made for selective space absorption. $C$, however, requires the small supplementary correction for absorption given in column (4), Table 9, whose origin is explained in section v.

TABLE 9*a*

RESULTS FOR DWARF STARS

| HD Sp (1) | $C$ | | | | |
|---|---|---|---|---|---|
| | Obsd. (2) | δExt.NP (3) | δ$E$ (4) | 0 Air M (5) | Zenith (6) |
| G0 | + 0.42 | +0.039 | +0.004 | +0.463 | + 0.446 |
| G5 | 0.64 | .060 | .006 | 0.706 | 0.680 |
| G8 | 0.79 | .072 | .007 | 0.869 | 0.837 |
| K0 | 0.89 | .081 | .008 | 0.979 | 0.943 |
| K2 | 1.01 | .090 | .009 | 1.109 | 1.069 |
| K5 | +(1.24) | +0.105 | +0.010 | +1.355 | +(1.309) |

We thus arrive at final reduced values for the observed color indices: $C$, air mass 0 in column (5) and air mass 1 in column (6); $C_1$ in column (10); $C_2$ in column (14)—all of Table 9. A similar treatment of $C$ for dwarf stars appears in Table 9*a*.

## VIII. PROVISIONAL COLOR TEMPERATURES

These reduced results for $C$, $C_1$, and $C_2$ are the arguments for interpolating reciprocal temperatures from the various color-temperature curves defined by Table 3. The results thus found, with zero points slightly adjusted to make $c_2/T = 1.30$ for A5 stars (except for the $C_1$ series in which the color for A5 is slightly discordant), are in columns (1)–(5) of Table 10. One detail must be noted. Since the computed data for the $C$ system include the differential extinction (temperature effect) at the pole, the argument used to interpolate $c_2/T$ must also include the differential extinction, that is, the corrections in column (3), Table 9, are to be omitted, and only the sums of columns (2) and (4) are to be used. Column (3) is retained, however, since columns (5) and (6) are themselves of interest.

The differences between the values of the reciprocal temperatures from $C_1$ and $C_2$, in column (6), Table 10, although slightly systematic, average only $\pm 0.057$—the equivalent of $\pm 0.017$ in $C_1$ and $\pm 0.012$ in $C_2$. Since there is no cumulative effect in the differences with advancing spectral type, columns (4) and (5) are combined to form the means in column (7).

Comparison of column (7) with the values from the $C$ system (col. [2]) gives the differences in column (8). The conspicuous progression indicates a considerable differ-

ence in the temperature scales derived from the photoelectric colors and from those of the international system. With the zero points fixed at 11,000° for A5 stars, the corresponding gK0 temperatures, for example, are 3810° and 4090°. The equivalent differences in color index are 0.13 for $C$, 0.07 for $C_1$, and 0.04 for $C_2$. Observational errors of these amounts are inadmissible.

In seeking an explanation of this disagreement, departures from black-body radiation and several approximations made in computing the theoretical colors must be considered. Peculiarities of radiation must remain largely speculative and are left as a last resort. Of the other uncertainties, however, something may be learned.

TABLE 10

PROVISIONAL COLOR TEMPERATURES

| HD Sp (1) | $c_2/T$ Giants* (2) | $c_2/T$ Dwarfs (3) | $c_2/T_1$ Giants (4) | $c_2/T_2$ Giants (5) | Diff. Col. (4) − Col. (5) (6) | Mean (4), (5) (7) | Diff. Col. (2) − Col. (7) (8) |
|---|---|---|---|---|---|---|---|
| B5 | 0.50$^5$ | ..... | 0.53 | 0.61 | −0.08 | 0.57 | −0.07 |
| A0 | 0.99$^5$ | ..... | 0.85 | 0.94 | − .09 | 0.89$^5$ | + .10 |
| A2 | 1.20$^5$ | ..... | 1.07 | 1.09 | − .02 | 1.08 | + .12 |
| A5 | 1.30 | ..... | 1.35 | 1.30 | + .05 | 1.32$^5$ | − .02 |
| F0 | 1.54$^5$ | ..... | 1.63 | 1.64 | − .01 | 1.63$^5$ | − .09 |
| F5 | 1.82$^5$ | ..... | 1.95 | 2.01 | − .06 | 1.98 | − .16 |
| G0 | 2.52 | 2.13$^5$ | 2.55 | 2.49 | + .06 | 2.52 | .00 |
| G5 | 2.88$^5$ | 2.58 | 3.16 | 2.99 | + .17 | 3.07$^5$ | − .19 |
| G8 | 3.16 | 2.88$^5$ | 3.45 | 3.40 | + .05 | 3.42$^5$ | − .26 |
| K0 | 3.50 | 3.08$^5$ | 3.75 | 3.77 | − .02 | 3.76 | − .26 |
| K2 | 3.92$^5$ | 3.34$^5$ | 4.14 | 4.20 | − .06 | 4.17 | − .25 |
| K5 | 4.39 | 3.82$^5$ | 4.94 | 4.93 | +0.01 | 4.93$^5$ | −0.54 |

* Strictly speaking, the results for B5–F0 in col. (2) and for G0–K5 in col. (3) are for main-sequence stars. The grouping used was adopted in order that cols. (2), (4), and (5) might be compared directly.

## IX. INFLUENCE OF APPROXIMATIONS

The approximations include the substitution of the Eastman 40 plate for the Seed 27 (affecting the computed $C$), the use of a questionable absorption for the Madison refractor ($C_1$), and the adoption of the sensitivity-curve of the Madison photocell for calculations involving the cell used at Mount Wilson ($C_2$). Finally, there is the considerable uncertainty in the zero point of the photovisual effective wave lengths $\lambda_{Pv}$, also affecting $C$. The corresponding errors cannot be completely determined, but certain interrelations can be found from which a statistical solution may be obtained. The detailed discussion follows.

From the observations of NPS stars (sec. ii) we have, zero point disregarded,[22]

$$Pg_{27s} - Pe_{wa} = +0.20C_{PgPv}\,, \qquad Pe_{wa} - Pe_{mr} = +0.075C_{PgPv}\,, \qquad (22)$$

in which the subscripts, as before, indicate the conditions of observation. The magnitudes and colors are observed values and must be corrected for absorption and differential extinction by equations (16) and (17) and by the data in Table 5. All values were reduced to zero air mass by using the corrections for the pole itself. The color excess $E$, required for (16) and (17) and as an absorption correction for $C$, was taken from data

[22] Stebbins and Whitford, *Mt. W. Contr.*, No. 586; *Ap. J.*, **87**, 237, 1938; Seares, *Mt. W. Contr.*, No. 587; *Ap. J.*, **87**, 257, 1938. The second equation, from Stebbins' data in Table 7, *Contr.* No. 586, is the equivalent of his equation (6).

used for *Mt. W. Contr.*, No. 684. Theoretically, $E$ is also affected by differential extinction; and, although the corrections are appreciable, they do not sensibly affect the present calculations. The factors $F$ and $F_1$ are in Table 7. The net result of all these corrections is to change the right-hand members of equations (22) to $+0.253C$ and $+0.073C$, respectively.

For the present we shall consider the relations for a temperature of 4000° only (zero point at 11,000°, as always), approximately that of a gK0 star. To utilize equations (22), we introduce $C_K$, the color for gK0, and immediately express it in terms of the color index for 4000°, proceeding as follows: For 11,000° and 4000°, $c_2/T = 1.303$ and 3.582, respectively, with a difference of 2.279. For gK0, write

$$\frac{c_2}{T} = 3.582 + t. \tag{23}$$

Then, since $C$ is nearly proportional to the reciprocal temperature and $t$ is small,

$$C_K = \frac{2.279 + t}{2.279} C_{4000} = 1.241\,(1 + 0.465t). \tag{24}$$

Equations (22) have been reduced to zero air mass; hence $C_{4000}$ must also be so reduced. The extinction 0.100 mag., from column (6), Table 5, applied to the value of $C$, column (7), bottom of Table 3, gives the value 1.241. Combining equation (24) with the revised right members of (22), we obtain

$$\mathrm{Pg}_{27s} - \mathrm{Pe}_{wa} = +0.314 + 0.146t, \tag{25}$$

$$\mathrm{Pe}_{wa} - \mathrm{Pe}_{mr} = +0.091 + 0.042t, \tag{26}$$

in which the left-hand members consist of quantities for which approximations or substitutions have been used in the calculations.

From the values of $\lambda_e$ for 4000° in the middle and bottom sections of Table 3 and the corresponding $k$'s we find by formula (7) the $\mathrm{Pg}_{27s} - \mathrm{Pe}_{wa}$ color equation, whence, after correction for differential extinction,

$$\mathrm{Pg}_{40s} - \mathrm{Pe}_{ms} = +0.295. \tag{27}$$

The extinction correction, +0.103, from column (4), Table 5, refers to the Pg term alone; the second term needs none, since all the Pe calculations were made for zero air mass. Further, from column (9), Table 4 (4000° relative to 11,000°), and from column (8), bottom of Table 3, we obtain

$$\mathrm{Pe}_{ma} - \mathrm{Pe}_{ms} = +0.045, \tag{28}$$

$$\mathrm{Pe}_{ms} - \mathrm{Pe}_{mr'} = +0.022. \tag{29}$$

To simplify the notation, write

$$\left.\begin{aligned} p &= \mathrm{Pg}_{27s} - \mathrm{Pg}_{40s}\ \text{(plate error)}, \\ a &= \mathrm{Pe}_{mr} - \mathrm{Pe}_{mr'}\ \text{(refractor absorption error)}, \\ c &= \mathrm{Pe}_{wa} - \mathrm{Pe}_{ma}\ \text{(photocell error)}. \end{aligned}\right\} \tag{30}$$

Combining the foregoing equations, we obtain, first, from (25) + (26) − (27) − (29) and then from (25) − (27) + (28)

$$\left.\begin{aligned} p - a &= +0.088 + 0.188t, \\ p - c &= +0.064 + 0.146t. \end{aligned}\right\} \tag{31}$$

Further, for temperatures near 4000°, we may write the simple proportionality

$$\frac{c_2}{T'} - 1.303 = \frac{2.279}{1.241} C_{40s} . \tag{32}$$

For $T' = 4000°$, $C_{40s} = 1.241$, the value used in equation (24). Equation (32) corresponds to the calculated values in Table 3, corrected for differential extinction. $T'$ refers specifically to the Eastman 40 plate. For the Seed 27 plate the corresponding formula would contain the required temperature $T$, $C_{27s}$, and, in the denominator, an increment $i$ such that for $T = 4000°$, $C_{27s} = 1.241 + i$. Hence

$$i = C_{27s} - C_{40s} = \mathrm{Pg}_{27s} - \mathrm{Pg}_{40s} = p . \tag{33}$$

If now we substitute into both equation (32) and its analogue the color index $C_K$ for a gK0 star, we obtain the temperatures $T'$ and $T$ corresponding to the Eastman 40 and the Seed 27 plates. The difference of the formulae gives

$$\frac{c_2}{T} - \frac{c_2}{T'} = 2.279 C_K \left( \frac{1}{1.241 + p} - \frac{1}{1.241} \right). \tag{34}$$

Then, from (23) and a similar formula for $T'$, we have, with sufficient accuracy,

$$t - t' = -\frac{2.279}{1.241} \cdot \frac{C_K p}{1.241} . \tag{35}$$

From column (2), Table 10, $c_2/T'$ for gK0 is 3.50. Hence $t' = 3.50 - 3.582 = -0.08$. Further, $C_K$ for zero air mass (col. [5], Table 9) (relative to A5, taken as corresponding to 11,000°), is 1.303. We thus obtain

$$t = -0.08 - 1.78p \tag{36}$$

and, on substituting into equation (31), find

$$\left.\begin{aligned} +1.34p - a &= +0.073 , \\ +1.26p - c &= +0.052 . \end{aligned}\right\} \tag{37}$$

A similar treatment of the $C_1$ and $C_2$ data gives

$$\left.\begin{aligned} t_1 &= +0.17 - 4.04a' , \\ t_2 &= +0.19 - 6.41c' , \end{aligned}\right\} \tag{38}$$

in which, in analogy with formulae (30),

$$a' = C_{mr} - C_{mr'} , \qquad c' = C_{wa} - C_{ma} . \tag{39}$$

At this point two additional complications must be taken into account: It is none too certain that the sensitivity-curve of the Eastman 40 plate applies strictly to the conditions of observation, and, second, the calculations involving silvered mirrors are for fresh surfaces, whereas the observational data refer to an average state after resilvering at six months' intervals.

To introduce these factors let

$$\mathrm{Pg}'_{40s} + \alpha = \mathrm{Pg}_{40s} , \qquad \mathrm{Pg}'_{27s} + \beta = \mathrm{Pg}_{27s} , \tag{40}$$

where $\mathrm{Pg}'_{40s}$, calculated with a possibly erroneous sensitivity-curve, and $\mathrm{Pg}'_{27s}$, observed and including the effect of any tarnish on the mirrors, replace, respectively, the magni-

tudes hitherto designated by $Pg_{40s}$ and $Pg_{27s}$. The corrections $\alpha$ and $\beta$, like $p$, $a$, and $c$, refer to a temperature of 4000° (relative to 11,000°). Strictly speaking, $\beta$, as it enters into the formulae, refers to a gK0 star. The difference, however, is negligible.

From the definition of $p$ in formulae (30), it appears at first sight as though full allowance could be made for these additional errors by replacing $p$ in equations (36) and (37) by $p + \alpha - \beta$. For (36) this is the case, as may be seen by retracing the steps from equation (32) on; but not so for (37). For the latter the correct relations are obtained by noting that the left member of equation (25) is now (omitting subscripts) $Pg' - Pe$ or, by equation (40), $Pg - \beta - Pe$. Hence, (25) is reduced to the corrected form simply by adding $\beta$ to both members of the equation. In other words, any errors arising from the use of incorrect data for the right member, of equation (26) as well as of (25), must eventually cancel, as in fact they do, when their influence is traced through in detail. The only other term affected in the several equations is the first on the left of (27), which includes $\alpha$.

In place of equation (36) we thus find

$$t = -0.08 - 1.78\,(p + \epsilon)\,, \tag{41}$$

where

$$\epsilon = \alpha - \beta\,, \tag{42}$$

and, instead of (37),

$$\left.\begin{aligned} a - \epsilon &= 1.34p - 0.073\,, \\ c - \epsilon &= 1.26p - 0.052\,. \end{aligned}\right\} \tag{43}$$

The question of silver tarnish also enters into the results for $C_2$ and might thus affect the second equation of (38). There is reason to believe, however, that here its influence is entirely negligible. In any case the equation can be used only as a general control on the results from the first of (38).

Formulae (41)–(43), together with (38), summarize the results thus far obtained. It is now necessary to estimate the influence of $p$, $a$, $c$, etc., on the values calculated for $t$, $t_1$, and $t_2$.

Equations (38) are difficult to handle, since the color indices in (39) have no terms in common, as in the case of equation (33). Consequently, although obviously related to $a$ and $c$, $a'$ and $c'$ cannot be expressed in terms of these quantities. For a common type of difference in glass absorption-curves—a progressive divergence toward the violet—$a'$ would be about $a/2$. As an analogous case, note the effect of differential extinction (4000°–11,000°) on $C_2$ (Table 6), and on Pe (col. [9], Table 5) (+0.011 as against +0.021 mag.); or, again, of the change from silver to aluminum surfaces (cols. [10] and [9], Table 4) (+0.020 and +0.045 mag.). Presumptive values of $c'$, on the other hand, cannot be assigned, and the second of equations (38) remains intractable, at least in respect to exact information on $t_2$. For further discussion equations (38) may be written

$$\left.\begin{aligned} t_1 &= +0.17 - 4.04na\,, \\ t_2 &= +0.19 - 6.41n'c\,. \end{aligned}\right\} \tag{44}$$

The other equations lead to a more definite result, for, although $p$, $\epsilon$, $a$, etc., cannot be determined individually, they need not be disregarded altogether. For orientation it may be recalled that these quantities are defined by equations (30), (39), and (42) and that their values, expressed in magnitudes, are for a star of 4000° temperature relative to one of 11,000°.

We may say with some assurance that $-3 < p < +3$ (for the present we take 0.01 as unit), otherwise magnitudes obtained with the Eastman 40 plate would have shown an appreciable color equation relative to the international system. Further, under the favorable conditions on Mount Wilson and with resilvering at six months' intervals,

the effect of tarnish, necessarily positive, must be very small. The adopted limits are $0 < \beta < +2$. The conditions are such that, if the upper limit has been underestimated, the actual uncertainty in $t$ will be less than that calculated. Finally, we assign a lower limit for $a$ (absorption correction) and an upper limit for $\alpha$ (sensitivity-curve). Values of $-7$ and $+7$, respectively, are probably safe. The other limits are then given by equations (42) and (43), and we have all together

$$\begin{aligned} -3 < p < +3\,, \quad & -2 < a < +7\,, \\ 0 < \beta < +2\,, \quad & -4 < \epsilon < +5\,, \\ -7 < a < +2\,, \quad & -5.2 < c < +3.8\,. \end{aligned}$$

The probable effect of these quantities on $t$, $t_1$, and $t_2$ (note the restriction on $t_2$ already mentioned) may be found from a table of solutions giving values of $a$ and $c$ computed from equations (43) for integral values of $p$ and $\epsilon$. From this table it appears that the maximum frequency of $p$ and of $\epsilon$ occurs for their maximum values but that the distributions of $p + \epsilon$ (the quantity required), $a$, and $c$ rise to sharply defined maxima. These unknowns can therefore be treated as observed quantities affected by errors of observation.

Since the distributions are skew, it would be preferable from the standpoint of probabilities to use median values, but the medians do not satisfy equations (43), and we are obliged to use means. The difference, however, is of minor importance. The mean values and the average and the maximum deviations are (unit, 0.01):

$$\left.\begin{aligned} \bar{p} &= +0.92 \pm 1.50\,; && -3.9\,, && +2.1\,, \\ \bar{\epsilon} &= +2.02 \pm 2.02\,; && -6.0\,, && +3.0\,, \\ \overline{p+\epsilon} &= +2.95 \pm 1.80\,; && -4.0\,, && +5.0\,, \\ \left.\begin{aligned} \bar{a} &= -3.94 \\ \bar{c} &= -2.00 \end{aligned}\right\} &\pm 2.01\,; && -3.0\,, && +5.7\,. \end{aligned}\right\} \tag{45}$$

For assumed values of $n = n'$, formulae (41) and (44) then give (except the last two lines)

$$t = -0.13 \pm 0.032\ (\mathrm{AD})\,,$$

$$\left.\begin{aligned} n,\, n' &= +\tfrac{1}{2} && +\tfrac{1}{4} && 0 && -\tfrac{1}{4} && -\tfrac{1}{2}\,, \\ t_1 &= +0.25 && +0.21 && +0.17 && +0.13 && +0.09\,, \\ t_2 &= +0.25 && +0.22 && +0.19 && +0.16 && +0.13\,, \\ t_1 - t &= +0.38 && +0.34 && +0.30 && +0.26 && +0.22\,, \\ \mathrm{Min},\, t_1 - t &= +0.36 && +0.30 && +0.23 && +0.16 && +0.09\,, \\ \mathrm{Equiv.}\ \Delta\lambda_{Pv} &= -206 && -171 && -131 && -92 && -51A\,. \end{aligned}\right\} \tag{46}$$

The average deviations for $n = \pm\frac{1}{2}$ are: $t_1$, $\pm 0.041$; $t_2$, $\pm 0.065$; for $n = \pm\frac{1}{4}$, one-half these amounts. To obtain reciprocal temperatures for gK0, 3.58, the value for 4000°, is to be added to the $t$'s.

The assumption that $n = n'$, in other words, that $c'/c = a'/a$, is perhaps as good as any. At least it brings $t_1$ and $t_2$ into agreement for the most probable value of $n$. By assuming $t_1 = t_2$ and disregarding the difference in the absolute terms of equations (44), we obtain $n' = 0.63\ n$. This ratio gives $t_2 - t_1 = +0.02$ for all values of $n$. Hence the tacit assumption that $n'/n$ is independent of $n$ contradicts the supposition that $t_1 = t_2$, and we cannot tell whether the 0.02 difference represents accidental error or the influence of $c'$. Owing to this uncertainty, the values of $t_2$ give only a general confirmation of

those for $t_1$ and may be dropped for the present. The quantity $c' = n'c$ therefore seems to lie between $-1.3n$ and $-2n$, where, at a maximum, $n$ may be taken as $\frac{1}{2}$.

The values of $t_1 - t$, third line from the bottom of formulae (46), show that the disagreement of $t_1$ and $t$ has generally been increased by taking account of $p + \epsilon$ and $a$. Only for the very improbable ratio $-\frac{1}{2}$ has there been a slight improvement (0.22 as against 0.25). To make this statistical result conclusive, however, it must be shown that none of the less probable solutions of equation (43) can greatly diminish the values of $t_1 - t$.

From equation (41) and the first of (44),

$$t_1 - t = +0.25 \mp 1.78\,(a \mp p \mp \epsilon) \mp 0.24a\,, \qquad (n = \pm\tfrac{1}{2})\,. \tag{47}$$

For $n = \pm\frac{1}{4}$, the equation remains the same, except that $\pm 0.77a$ replaces $\mp 0.24a$. These formulae and the table of solutions then give the minimum possible values of $t_1 - t$ shown in the last line but one of formulae (46). Even the smallest of these is well above zero. Hence none of the solutions consistent with the limits for the unknowns can bring $t_1$ and $t$ into agreement; and for the most probable ratio $n = +\frac{1}{2}$, and even for $+\frac{1}{4}$, the discordance is nearly as great as for the preferential solution represented by the mean values of the unknowns.

Nor can any reasonable uncertainty in the photovisual effective wave lengths account for the discordance. If the accepted values of $\lambda_{Pv}$ could be decreased, $C_{4000}$ would be decreased. The reciprocal temperature for gK0, and hence $t$, would then be increased. The minimum changes in $\lambda_{Pv}$ required to make $t_1 = t$ are in the last line of formulae (46), immediately below the minimum values of $t_1 - t$ on which they are based. The zero point for $\lambda_{Pv}$ is admittedly less certain than that for $\lambda_{Pg}$, but by no such amount as these figures would demand.

As matters stand at present, we have the values of $t$ and $t_1$ shown in equations (46). The corresponding temperatures and their respective deviations, both average and maximum, are given in (48).

$$T = 4154° \pm 36°\,; \quad -106°\,, \quad +86°$$

| $n =$ | $+\frac{1}{2}$ | $+\frac{1}{4}$ | 0 | $-\frac{1}{4}$ | $-\frac{1}{2}$ |
|---|---|---|---|---|---|
| $T_1 =$ | 3742° | 3781° | 3821° | 3863° | 3905° |
| Av. dev. = | ± 39 | ± 20 | .... | ± 20 | ± 43 |
| Max. dev. = | − 114 | − 59 | .... | − 31 | − 63 |
| | + 59 | + 30 | .... | + 65 | + 132 |

(48)

## X. OBSERVATIONAL ERRORS AND TOTAL UNCERTAINTY

The results in formulae (48) presuppose, however, the accuracy of equations (41), (43), and (44) or, for the present purpose, of the simpler forms (36), (37), and (38). Most of the quantities involved in these formulae are computed from data which, relatively speaking, may be regarded as error-free. An exception is $\lambda_{Pv}$, to be allowed for later. Only the coefficients of the right-hand members of equations (22) and the color index for gK0 stars in these equations and in (35) include errors of measurement whose influence must be traced.

The mean errors of the coefficients in equations (22) are $\pm 0.005$ and $\pm 0.010$, respectively. Corrected for absorption, etc., the right members of (22) become

$$(0.253 \pm 0.006)\,C_K'\,, \quad (0.073 \pm 0.010)\,C_K'\,,$$

the true color index being $C_K = C_K' + \delta C$, and $\delta C$ the correction to the observed value $C_K'$.

Equation (35) and its analogues show that (36) and (38) require on the right the corrective terms (second-order quantities neglected throughout)

$$+1.8\,\delta C\,, \qquad +3.8\,\delta C_1\,, \qquad +5.9\,\delta C_2\,. \tag{49}$$

These quantities arise from the absolute terms in (36) and (38) and have nothing to do with the solution for $p + \epsilon$, $a$, and $c$.

Returning to equations (22), we find for the right-hand members of (25) and (26), since by (24) $C'_K = 1.241\,(1 + 0.465t) - \delta C$, the additional terms

$$\pm 0.007 - 0.25\,\delta C\,, \qquad \pm 0.012 - 0.07\,\delta C\,;$$

and, for equation (31),

$$\pm 0.007 \pm 0.012 - 0.32\,\delta C\,, \qquad \pm 0.007 - 0.25\,\delta C\,.$$

The $t$ in equation (31) is the true value and is to be replaced by that from (36) plus the correction $+1.8\delta C$ from equation (49). This substitution eliminates $\delta C$ altogether and leaves for the right-hand members of (37) only the influence of the errors in the coefficients of (22).

The corrections to equation (37), designated by $\gamma_1$ and $\gamma_2$, respectively, are

$$\gamma_1 = \pm\,\gamma_2 \pm 0.012\,, \qquad \gamma_2 = \pm\,0.007\,. \tag{50}$$

These conclusions apply equally well to the expanded formulae involving $\epsilon$; that is, the corrections (49) are to be added to equations (41) and (44), while (43) require $-\gamma_1$ and $-\gamma_2$, respectively. Errors in the color indices therefore affect only the first terms for the $t$'s; $\gamma_1$ and $\gamma_2$, only the solution for $\overline{p + \epsilon}$, $\bar{a}$, and $\bar{c}$.

To determine the effect of the corrections on these quantities, consider the first of equations (43) for a special value of $p$, say, $+0.03$, giving

$$\epsilon = +0.033 + \gamma_1 + a\,. \tag{51}$$

Since the lower limit of $a$ remains at $-0.07$, the lower limit of $\epsilon$ is raised above its original value by the amount $\gamma_1$. The upper limit of $\epsilon = \alpha - \beta$ remains unchanged, however. Consequently, the upper limit of $a$ is lowered by $\gamma_1$. The range for both $\epsilon$ and $a$ is therefore decreased by this amount; $\bar{\epsilon}$, and hence $\overline{p + \epsilon}$, is increased by $\gamma_1/2$, while $a$ is decreased by $\gamma_1/2$.

Similarly, from the second of equations (43), again for $p = +0.03$, we find

$$c = \epsilon - 0.014 - \gamma_2\,. \tag{52}$$

Since the lower limit of $\epsilon$ has been raised by $\gamma_1$, the lower limit of $c$ is raised by the same amount; but, in addition, this and every other value of $c$, including the upper limit, are diminished by $\gamma_2$. The correction to $c$ is therefore $+\frac{1}{2}\gamma_1 - \gamma_2$. These conclusions are independent of the numerical terms in equations (51) and (52), and hence of $p$; a definite value of $p$ was used only for clarity.

Multiplying these corrections by the coefficients in equations (41) and (44) and adding the terms in (49), we obtain the total corrections for observational error required by the $t$'s:

$$\left.\begin{aligned} \delta t &= +1.8\,\delta C - 0.9\gamma_1\,, \\ \delta t_1 &= +3.8\,\delta C_1 + 2.0n\gamma_1\,, \\ \delta t_2 &= +5.9\,\delta C_2 - 6.4n'(\tfrac{1}{2}\gamma_1 - \gamma_2)\,. \end{aligned}\right\} \tag{53}$$

For the ME in $C$, take $\pm 0.02$; for that in $C_1$ and in $C_2$, $\pm 0.01$. Using the values for $\gamma_1$ and $\gamma_2$ in equations (50), we then have, for $n' = n = +\frac{1}{2}$, the following component and combined ME's of observational origin:

| | | Combined ME |
|---|---|---|
| $\delta t$ , | $\pm 0.036 \mp 0.006 \mp 0.011$ ; | $\pm 0.038$ , |
| $\delta t_1$ , | $\pm 0.038 \pm 0.007 \pm 0.012$ ; | $\pm 0.040$ , |
| $\delta t_2$ , | $\pm 0.059 \pm 0.011 \mp 0.019$ ; | $\pm 0.063$ . |

(54)

For $n = n' = +\frac{1}{4}$ the results are only a little smaller because of the dominance of the first of the corrective terms; the errors originating in equations (22), in the end, are of little effect. The precision for $t$ and $t_1$ is approximately the same. The uncertainty for $t_2$ reflects the influence of the shorter "base line" for the $C_2$ colors.

*Total uncertainty.*—Besides these observational errors, we have the uncertainty arising from the dispersion in $p + \epsilon$, $a$, and $c$, given in connection with formulae (46) as average deviations in the reciprocal temperatures, and in (48) in the temperatures themselves. Further, allowance must be made in $t$ for the ME of $\lambda_{Pv}$, for which $\pm 20$ A, or $\pm 0.036$ in $t$, is used. Multiplying the average deviations in equation (46) by 5/4 to obtain ME's, we have for the component and total ME's from all sources

| | | Total ME |
|---|---|---|
| $t$ , | $\pm 0.040 \pm 0.038 \pm 0.036$ ; | $\pm 0.066$ , |
| $t_1$ , | $\pm 0.051 \pm 0.040$ ; | $\pm 0.065$ , |
| $t$ , | $\pm 0.081 \pm 0.063$ ; | $\pm 0.103$ . |

(55)

## XI. RESULTS FOR gK0 STARS: DEPARTURES FROM BLACK-BODY RADIATION

The adopted value for $t_1$ depends on the choice for $n$, which in all probability lies close to $+\frac{1}{2}$. Indeed, the chief reason for including other ratios in the calculations has been to show that their influence on $t_1$ is only moderate and that even highly improbable values cannot wholly account for the discrepancy between $t$ and the generally accordant values for $t_1$ and $t_2$.

As the result for gK0 stars, we have the following temperatures and ME's:

$$\left.\begin{aligned} c_2/T &= 3.45 \pm 0.066 , \qquad T = 4150° \pm 80° , \\ c_2/T_1 &= 3.82 \pm 0.065 , \qquad T_1 = 3750 \pm 64 . \end{aligned}\right\} \tag{56}$$

To account for the difference of 400°, apparently we must admit departures from the underlying assumption of black-body radiation, which, in some degree at least, were to be expected from the beginning. For a representative temperature of 9000° the intervals in $\lambda_e$ for the three color systems are (Table 3):

$C$ , 4272–5430 ; $C_1$ , 4240–4741 ; $C_2$ , 4319–4645 .

The violet ends of these "base lines" for $C$ and $C_1$ are nearly the same, but the red end for $C$ extends 700 A beyond that for $C_1$. The increasing concentration of absorption lines toward the violet, if nothing else, might therefore produce a steeper color gradient within the interval for $C_1$ as compared with that for $C$. The interval for $C_2$, however, falls almost centrally within that for $C_1$. Here any difference in color gradient would be small and probably beyond the precision of even the photocell. Qualitatively, the explanation is satisfactory and at present seems to be the only one possible.

### XII. COLLECTED RESULTS FOR COLOR TEMPERATURE

The results for gK0 stars can be adapted to stars of other types by noting that the corrections to the provisional reciprocal temperatures in Table 10 should be proportional to these temperatures. For gK0 we have found $-0.05$ for $c_2/T$ and $+0.07$ for $c_2/T_1$. These values lead to the corrected results in columns (2)–(4) in Table 11. Although $t_2$ did not contribute directly to the determination of the temperature for gK0, a reasonable value for $c'$ brought $t_2$ into agreement with $t_1$. Moreover, as just suggested, such agreement is to be expected, even if the radiation departs from the black-body ideal, not only for gK0, but for other types as well. The differences between $c_2/T_1$ and $c_2/T_2$ given in column (6), Table 10, are therefore still to be regarded as accidental errors. Hence the mean reciprocal temperatures in column (7), Table 10, are used as the basis for the adopted photoelectric results in column (4), Table 11.

TABLE 11

ADOPTED COLOR TEMPERATURES

| HD Sp | Corrected $c_2/T$ | | | Diff. Col. (2) − Col. (4) | Col. (5) Corrected for Linear Divergence | Temperature | | |
|---|---|---|---|---|---|---|---|---|
| | Int. System | | Photoelectric, Giants | | | Int. System | | Photoelectric, Giants |
| | Giants* | Dwarfs | | | | Giants | Dwarfs | |
| (1) | (2) | (3) | (4) | (5) | (6) | (7) | (8) | (9) |
| B5 | 0.52 | ..... | 0.55 | −0.03 | −0.14 | 27500° | ..... | 26000° |
| A0 | 1.00 | ..... | 0.88[5] | + .12 | + .06 | 14300 | ..... | 16200 |
| A2 | 1.21 | ..... | 1.07[5] | + .13 | + .10 | 11800 | ..... | 13300 |
| A5 | 1.30 | ..... | 1.33 | − .03 | − .02 | 11000 | ..... | 10800 |
| F0 | 1.54 | ..... | 1.64 | − .10 | − .05 | 9300 | ..... | 8750 |
| F5 | 1.81 | ..... | 2.00 | − .19 | − .08 | 7900 | ..... | 7200 |
| G0 | 2.55 | 2.12 | 2.55 | .00 | + .18 | 5610 | 6750° | 5620 |
| G5 | 2.85 | 2.55 | 3.12 | − .27 | .00 | 5030 | 5610 | 4590 |
| G8 | 3.12 | 2.85 | 3.48 | − .36 | − .04 | 4580 | 5030 | 4120 |
| K0 | 3.45 | 3.05 | 3.82 | − .37 | .00 | 4150 | 4690 | 3750 |
| K2 | 3.87 | 3.30 | 4.24 | − .37 | + .06 | 3700 | 4340 | 3380 |
| K5 | 4.32 | 3.77 | 5.02[5] | −0.70 | −0.15 | 3310 | 3790 | 2850 |

* See note to Table 10.

The divergence between the corrected values (cols. [2] and [4] of this table), shown in column (5), is, of course, larger than that for the uncorrected results (col. [8], Table 10), because of the increased difference for gK0 arising from the influence of $p + \epsilon$, $a$, and $c$. If this divergence is due to departures from black-body radiation, as seems likely, there is no reason to expect a linear progression with spectral type or with reciprocal temperature; and yet, when such a relation (for $c_2/T$) is used to reduce the photoelectric results to the temperature scale of the photographic series, only moderate residuals remain, as shown in column (6), Table 11. Accidental error doubtless plays a considerable part, but it is difficult to account for all the differences in this way. Moreover, the positive values for early A stars strongly suggest the influence of hydrogen absorption, which affects $C$, but not $C_1$ or $C_2$.

The root mean square of these differences, $\pm 0.087$, can be checked against the ME's adopted for the color indices. The effect of these errors on the $t$'s is expressed by the first terms of the sequences in equations (54), from which for differences of the form $t - (t_1 + t_2)/2$, we find a ME of $\pm 0.061$. Since the root mean square, $\pm 0.087$, includes the differential effect of any spectral peculiarities, such as hydrogen absorption or other departures from black-body radiation, the agreement is satisfactory. The comparison

cannot be carried further, because all the other errors covered by the values in (54) and (55) affect the relative temperature scale and are included in the linear corrections used to obtain the differences in column (6), Table 11.

Finally, it may be recalled that the zero point for the temperature scale has been fixed by the assumption that type A5 corresponds to 11,000°. Any adjustment required by more conclusive evidence may be made by applying a constant correction to the values of $c_2/T$. The temperatures in the last three columns of Table 11 correspond to the adopted color indices, without smoothing. The value 10,800°, instead of 11,000°, in the last column reflects the slight discordance in $C_1$ for A5, probably the result of an error in the mean type.

### XIII. RELATION OF ISOPHOTAL TO MEAN EFFECTIVE WAVE LENGTHS

The factor $k_B$ in the first (for illustration) of equations (5) depends on $T$ (as well as on $s_B$) in a manner determined by the mean effective wave length defined by equation (4). We may, however, suppose $k_B$ to be independent of $T$ (but not of $s_B$) and change the definition of $\lambda_B$ accordingly. The result is Brill's[23] isophotal wave length $\lambda_i$, which for the temperature $T$ defines the integrated magnitude $m_B$ corresponding to the sensitivity function $s_B$. For this case, and in fact for any system, formula (6) may be written

$$k y_i = \Sigma s y , \tag{57}$$

where, as just noted, $k$ is independent of $T$, and $y_i$ is the value from Table 1 for temperature $T$ and the isophotal wave length $\lambda_i$.

For some temperature $T_0$, usually around 5000° to 7000°, $y_i$ attains its maximum value of unity. The coefficient $k$ is therefore equal to the maximum $\Sigma sy$, the value for $T_0$. Hence

$$y_i = \frac{(\Sigma s y)_T}{(\Sigma s y)_{T_0}} , \tag{58}$$

from which the values of $\lambda_i$ may be computed for different values of $T$. The denominator of equation (58) may be found rather closely from the sequence of values for the numerator, and then quite exactly during the calculation of $\lambda_i$. The isophotal wave lengths are very nearly proportional to the reciprocal temperature and must run smoothly, near $T_0$ as elsewhere. In this region even a slight error in the value of the denominator produces a large irregularity in $\lambda_i$. Simple approximations quickly give the correct value.

To show that $\lambda_i$ from equation (58) satisfies Brill's own definition of an isophotal wave length, write $y_{iT_0}$ $(=1)$ in the denominator of the first member of the equation, $T'$ in both numerators, and $T_0'$ in the denominators. Then by formulae (1) and (2),

$$\frac{I_{iT}}{I_{iT_0}} = \frac{e_T}{e_{T_0}} ,$$

whence

$$-2.5 \log \frac{I_{iT}}{I_{iT_0}} = M_{iT} - M_{iT_0} = m_T - m_{T_0} ,$$

or

$$M_{iT} = m_T + (M_{iT_0} - m_{T_0}) . \tag{59}$$

The parenthesis is a constant, depending only on the characteristics of the magnitude system to which it belongs (photographic, photovisual, etc.). Its value is fixed by the sensitivity function $s = f(\lambda)$, or in practice by the sequence of values adopted for $s$.

[23] *Veröff. der Univ. Sternw. Berlin-Babelsberg*, **7**, Part V, 5, 1929.

Equation (59) states that for any temperature the intensity of black-body radiation of isophotal wave length $\lambda_i$, expressed in magnitudes, is equal to the integrated magnitude for that temperature, plus a constant; which is essentially Brill's definition.[23]

For two magnitude systems defined by the sensitivity functions $s_B$ and $s_Y$, the color index $C_{BY}$ from isophotal wave lengths is

$$C_{BY} = +2.5 \log y_{iB} + 2.5 \log y_{iY} + \text{const.}, \qquad (60)$$

which follows at once from equation (7), since in this case the $k$'s are independent of $T$ and may be combined with the constant.

With the aid of Table 1, the calculation of isophotal wave lengths from equation (59) and of color indices or color equations from (60) is a simple matter. The formulae are of considerable interest and have the advantage that the factor $k$ does not vary with $T$. The wave lengths themselves, however, are not so closely related to the characteristics of the radiation involved in the magnitudes of a particular system as are the mean effective wave lengths; and in the calculation of absorption effects they usually give less accurate results.

TABLE 12

ISOPHOTAL WAVE LENGTHS

| $T$* | $c_2/T$ | International | | Stebbins $C_2$ | | $T$* | $c_2/T$ | International | | Stebbins $C_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Pg (E40) | Pv | B | Y | | | Pg (E40) | Pv | B | Y |
| 22 | 0.65 | 4200 | 5424 | 4291 | 4628 | 6 | 2.39 | 4296 | 5439 | 4328 | 4655 |
| 17 | 0.84 | 4210 | 5426 | 4296 | 4630 | 5 | 2.87 | 4319 | 5443 | 4338 | 4661 |
| 13.7 | 1.05 | 4219 | 5427 | 4300 | 4632 | 4 | 3.58 | 4355 | 5445 | 4352 | 4673 |
| 11 | 1.30 | 4231 | 5428 | 4304 | 4634 | 3.5 | 4.09 | 4380 | 5448 | 4362 | 4684 |
| 9 | 1.59 | 4248 | 5431 | 4312 | 4640 | 3 | 4.78 | 4411 | 5454 | 4373 | 4697 |
| 7 | 2.05 | 4270 | 5435 | 4320 | 4648 | | | | | | |

* Unit, 1000°.

For comparison with the effective wave lengths of Table 3, isophotal values for the international system and for the $C_2$ color system of Stebbins are given in Table 12. The range in $\lambda_i$ is about one-half that in the corresponding effective wave lengths. The isophotal wave lengths thus depart widely from wave lengths measured with the objective grating (see n. 13). Generally there is agreement between $\lambda_i$ and $\lambda_e$ for some rather high temperature, while the largest differences occur for low temperatures. Color indices calculated from the values of $\lambda_i$ in Table 12 are identical with those in Table 3 found with $\lambda_e$.

The two-to-one ratio in the ranges for $\lambda_e$ and $\lambda_i$ is likely to prove a useful property. The results suggest that its value varies slowly from system to system with the value of $\lambda_i$ for a given $T$, say, 7000°. When this relationship is better known, it should be possible to determine $\lambda_e$ from values of $\lambda_i$, or vice versa, for magnitude systems for which the sensitivity factors are unknown. The isophotal wave lengths, it will be noted, can be found from equation (60) with the aid of Table 1 for any system whose color equation relative to the international system is known. In this connection the systematic relationships between the $k$'s of Tables 3 and 4 and the range in $\lambda_e$ mentioned at the end of section iii will also prove useful.

# SPECTROSCOPIC OBSERVATIONS OF T ARIETIS*

ALFRED H. JOY AND PAUL W. MERRILL
Mount Wilson Observatory
*Received August 14, 1943*

## ABSTRACT

Fifteen spectrograms of the Me variable T Arietis were obtained for a study of its spectrum and velocity. The spectral type varies from M6e to M8. Emission lines are present except near minimum, and their behavior is similar to that of the more regular Me stars. λλ 3852 *Fe* I, 3905 *Si* I, and 3938—? are comparatively strong, while hydrogen emission is weak. The radial velocities from the absorption lines have a range of 8.6 km/sec, but it is not certain that the variation is correlated with phase. The mean velocity is +7.1 km/sec. The mean displacement of the emission lines with respect to the absorption lines ($A-E$) is +6.5 km/sec, which is about 5 km/sec less than that found for typical Mira variables of the same period.

Variability of the light of T Arietis (024217) was discovered by G. F. J. A. Auwers in 1870. Although the light-changes are small compared with other Me variables of like period and the light-curve is irregular, the cycles are well defined and have been observed for many years. The period varies from 305 to 340 days, the maximum light from 7.4 to 9.3 mag., and the minimum light from 9.3 to 11.1 mag. The light-curve for the last three cycles, according to observers of the American Association of Variable Star Observers, is shown in Figure 1.

Peculiarities in the spectrum suggested that a spectroscopic study of the star would be of value. Fifteen spectrograms were obtained with spectrographs attached to the 60- and 100-inch reflectors during the period from August, 1940, to March, 1943. The dispersion is about 75 A/mm at $H\gamma$ except for the third plate, on which it is 40 A/mm.

The dates of the observations, the phases, the spectral types, and the velocities reduced to the sun are in Table 1. The phases are based on the immediately preceding minima shown in Figure 1. In general, the spectral type changes with phase, varying from M6e at maximum to M8 at minimum.

In determining the radial velocities from the absorption lines the average number of lines used was 30 per plate. All the spectrograms are of good quality and were measured by both authors. The results may be considered reliable within the errors which accompany low dispersion. The total range of velocity from the dark lines is 8.6 km/sec. Although it is not certain that the velocity varies with phase, changes from cycle to cycle are indicated. The mean velocity for observations of the first observing season (JD 2429856–2430009), which covers the descending branch of the light-curve and minimum, is +4.1 km/sec; for the second season (JD 2430249–423), near the time of minimum, +10.0 km/sec; and for the third season (JD 2430666–799), covering increasing light and maximum, +8.2 km/sec. The total range for each season is about 4 km/sec, or one-half that for the whole series.

Many of the emission lines usually found in Me variables are present in the spectrum of T Arietis except at minimum light. The lines λλ 3852 *Fe* I, 3905 *Si* I, and 3938—? are prominent as compared with the hydrogen lines at certain phases, but the hydrogen emission is less intense than in normal long-period variables. The series of low-temperature iron lines is not present, and λ 4571 *Mg* I is weak and its time of visibility short. The general behavior of the bright lines is similar to that of the typical Me variables, although in T Arietis the various phenomena occur somewhat earlier with respect to the light-curve.

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 686.

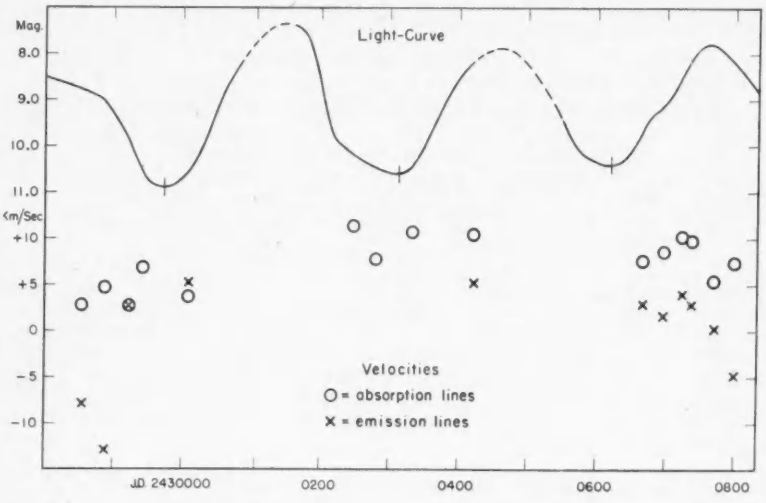


FIG. 1.—Light-curve of T Arietis (from American Association of Variable Star Observers) and radial velocities from bright and dark lines.

TABLE 1

OBSERVATIONS OF T ARIETIS

| PLATE | JULIAN DAY | PHASE FROM MIN. | SPECTRUM | VELOCITY | |
|---|---|---|---|---|---|
| | | | | Abs. | Em. |
| | | days | | km/sec | km/sec |
| γ 22853 | 2429856 | 201 | M6e | + 2.8 | − 7.8 |
| C 7581 | 9890 | 235 | M6e | + 4.7 | −12.8 |
| C 7619 | 9923 | 268 | M7e | + 2.7 | + 2.7 |
| γ 23160 | 9945 | 290 | M7 | + 6.8 | ..... |
| γ 23265 | 2430009 | 34 | M7e | + 3.7 | + 5.3 |
| E 253 | 0249 | 274 | M8 | +11.3 | ..... |
| γ 23819 | 0280 | 305 | M8 | + 7.8 | ..... |
| E 352 | 0334 | 21 | M8e | +10.6 | ..... |
| γ 24051 | 0423 | 110 | M6e | +10.4 | + 5.2 |
| γ 24663 | 0666 | 46 | M7e | + 7.6 | + 3.0 |
| γ 24745 | 0696 | 76 | M7e | + 8.6 | + 1.7 |
| E 724 | 0723 | 103 | M7e | +10.2 | + 4.0 |
| γ 24818 | 0737 | 117 | M6e | + 9.8 | + 2.9 |
| γ 24885 | 0771 | 151 | M6e | + 5.4 | + 0.3 |
| C 7700 | 0799 | 179 | M6e | + 7.4 | − 4.8 |
| Mean | ..... | ..... | ..... | + 7.1 | + 0.6 |

The limited amount of material available indicates that the bright lines occur as follows:

*Minimum.*—No emission.

*Minimum to maximum.*—λ 3905 and *Hδ* are first seen immediately after minimum. *Hγ*, *Hζ*, *Hη*, *Hθ*, *Hι*, λλ 3852, 3938, and 4102 *Si* I then appear in rapid succession as the star increases in brightness. All attain their greatest intensity shortly before maximum light.

*Maximum to minimum.*—After maximum these lines become fainter as the light of the star fades. *Hβ* and *Hε* appear, and the relative intensities of the Balmer lines approach the normal decrement toward the violet. λλ 4202 *Fe* I, 4307 *Fe* I, and 4571 *Mg* I are seen faintly about 100 days after maximum. All emission gradually disappears about a month before minimum.

On account of the small number of lines, the velocities from the emission lines are somewhat scattering. The total range is from −12.8 km/sec to +5.3 km/sec, with a weighted mean of +0.6 km/sec. The mean difference beween the absorption and emission lines ($A - E$) is +6.5 km/sec. This value is 5 km/sec smaller than would be expected for a typical Me variable with a period of 315 days according to Merrill's[1] displacement-curve.

From spectroscopic observations covering portions of three cycles we conclude that T Arietis is closely allied to the long-period variables but that it is abnormal in certain respects and may be intermediate between the regular and irregular M-type variables. The light-curve is peculiar and considerably irregular with a small range. The variations in velocity are small and may be irregular. The emission lines λλ 3852, 3905, and 3938 are well marked, although hydrogen emission is weaker than in typical Me variables. The spectroscopic absolute magnitude of the star determined from the lines used for giants of M type is −0.9, which is nearly the same as that of Mira.

[1] *Mt. W. Contr.*, No. 644; *Ap. J.*, **93**, 385, 1941.

# THE SPECTRUM OF BF CYGNI*

PAUL W. MERRILL
Mount Wilson Observatory
*Received September 1, 1943*

ABSTRACT

The variability of BF Cyg, discovered by C. R. d'Esterre, has recently been studied by Luigi Jacchia, who found a semiregular period of 754 days. Bright lines in the spectrum were discovered at Mount Wilson in 1925. A detailed study of line intensities and displacements is based on spectrograms taken in 1940, 1941, 1942, and 1943.

The star has a "combination" spectrum whose peculiarities differ in degree, rather than in kind, from those of Z And, AX Per, CI Cyg, and AG Peg. The intensities and displacements of numerous bright lines vary in a complex way. The chief lines studied are those of *H*, *He* I, *Fe* II, [*Fe* II], [*Fe* III], [*Ne* III], and [*O* III]. The *H* lines are very intense with a slow decrement. The lines of [*Fe* III] are stronger than in any other stellar spectrum yet observed. The nebular lines [*O* III] and [*Ne* III] are subject to surprisingly rapid variations in intensity, marked changes sometimes occurring within 24 hours. Many details concerning the behavior of these and other bright lines are recorded. Certain changes may possibly have some connection with the 754-day period of light-variation. An absorption spectrum, type about gM4, appeared on a few plates.

A comparative study of several objects is probably the best approach to the obscure problems of "combination" spectra.

The variability of BF Cygni was detected by C. R. d'Esterre[1] in 1914. The light-curve from 1890 to 1941, derived by Luigi Jacchia[2] from numerous photographs taken at Harvard, has several interesting features. According to Jacchia, during most of the 50-year interval the variation was semiregular, with an average period of 754 days. At times, however, the variation became very irregular or almost ceased. The semiregular fluctuation which reappeared in 1935 after 6 years of almost constant brightness was in phase with the earlier cycles. The amplitude of the 754-day cycle has been slightly greater than one magnitude; but a slower fluctuation, probably irregular, caused the total range to be four magnitudes (9.3–13.4).

On nearly all the nights on which spectrograms were obtained on Mount Wilson (Table 1), the magnitude[3] of BF Cyg was about 11.3. On the following nights it was about 11.8: October 1, October 16, and November 2, 1942; July 8 and August 12, 1943.

The *Hα* line was found to be bright[4] on an objective-prism spectrogram taken at Mount Wilson on September 21, 1925. The lines *Hβ* to *Hζ* were bright on a low-dispersion slit spectrogram taken by M. L. Humason on July 11, 1931. In the Mount Wilson catalogue[5] of Be and Ae stars the object was listed as MWC 315 (formerly called MW 187) with the remark: "The bright hydrogen lines are very intense. The decrement in intensity from *Hβ* to *Hζ* appears to be unusually small."

No further observations were obtained at Mount Wilson until 1940, when a curious circumstance again attracted attention to the star. On August 23, 1940, W. C. Miller, photographing with the 10-inch telescope and objective prism, found a previously un-

* *Contributions from the Mount Wilson Observatory, Carnegie Institution of Washington*, No. 687.

[1] *M.N.*, **75**, 292, 1915.

[2] *Harv. Bull.*, No. 915, 1941.

[3] Estimated by comparison with the faint star (Hagen's magnitude 11.4) which follows BF Cyg by 2′. These estimates made at the finder do not deserve high weight.

[4] Merrill, Humason, and Burwell, *Mt. W. Contr.*, No. 456; *Ap. J.*, **76**, 156, 1932.

[5] Merrill and Burwell, *Mt. W. Contr.*, No. 471; *Ap. J.*, **78**, 87, 1933.

observed bright line[6] which appeared to originate in an object 0.5′ south of and slightly preceding BF Cyg. No star to which the line could be ascribed appeared in the Ross atlas of the Milky Way or on a Franklin-Adams photograph. On August 30, 1940, M. L.

TABLE 1

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| Plate* | Date | JD 242 | Intensity | | | | | Radial Velocity (Km/Sec) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | *He* I | *Fe* II | [*Fe* II] | [*Fe* III] | [*O* III] | *H* | *He* I | *Fe* II | λ 4363 |
| γ 22932 | 1940 Sept. 10 | 9883 | 7 | 4 | 2 | 2 | 4 | +19 | + 5 | + 3 | −25 |
| C 7579 | 16 | 9889 | 4 | 3 | 1 | 3 | tr | +18 | + 9 | + 5 | −14 |
| C 7584† | 18 | 9891 | 5 | 3 | 1 | 3 | 2 | +18 | +10 | + 6 | −30 |
| γ 23031 | 26 | 9899 | 4 | 3 | 2 | 3 | 2 | +16 | + 9 | + 4 | −18 |
| γ 23074 | Oct. 13 | 9916 | 2 | 3 | 2 | 2 | 0 | +25 | +22 | − 1 | ..... |
| γ 23414 | 1941 May 13 | 0128‡ | 2 | tr | 3 | 5 | 0 | +26 | (+17) | ..... | ..... |
| E 120§ | 14 | 0129 | (2) | tr | 3 | (5) | (0) | +34 | (+32) | ..... | ..... |
| E 155§ | June 7 | 0153 | (2) | (0) | (3) | (6) | (0) | +28 | ..... | ..... | ..... |
| E 188 | July 12 | 0188 | 3 | 1 | 4 | 8 | 0 | +21 | +20 | −10 | ..... |
| E 212 | Aug. 6 | 0213 | 2 | tr | 4 | 6 | 0 | +19 | +19 | −12 | ..... |
| E 231 | 30 | 0237 | 5 | tr | 3 | 8 | 6 | +17 | + 1 | −10 | +23 |
| E 236 | 31 | 0238 | 4 | tr | 3 | 8 | 4 | +17 | +10 | − 8 | +22 |
| γ 23876 | Nov. 10 | 0309 | 3 | tr | 3 | 5 | 0 | +23 | (+31) | ..... | ..... |
| γ 24409 | 1942 Aug. 28 | 0600 | 2 | 2 | tr | 4 | 0 | 0 | +14 | + 4 | ..... |
| E 579 | Sept. 15 | 0618 | 3 | 2 | tr | 5 | 5 | − 2 | + 1 | + 6 | −29 |
| γ 24455 | 18 | 0621 | 4 | 2 | tr | 5 | 4 | + 5 | + 6 | + 7 | −23 |
| γ 24461 | 19 | 0622 | 4 | 2 | tr | 5 | 3 | + 6 | +12 | + 3 | −24 |
| γ 24467 | 20 | 0623 | 3 | 2 | tr | 5 | 2 | + 1 | + 9 | + 2 | −42 |
| γ 24471 | 21 | 0624 | 4 | 2 | tr | 5 | 2 | + 1 | + 7 | + 7 | −33 |
| γ 24476 | 22 | 0625 | 4 | 2 | tr | 5 | 4 | +10 | +10 | + 7 | −17 |
| γ 24481 | 23 | 0626 | 4 | 2 | tr | 5 | 6 | + 9 | − 2 | + 3 | −28 |
| γ 24487 | 24 | 0627 | 4 | 2 | tr | 5 | 5 | + 7 | + 5 | + 6 | −29 |
| γ 24497 | 26 | 0629 | 4 | 2 | tr | 5 | 4 | + 2 | + 7 | + 3 | −42 |
| γ 24505 | 27 | 0630 | 4 | 2 | tr | 5 | 2 | + 4 | +14 | + 4 | −30 |
| γ 24513 | 29 | 0632 | 3 | 2 | tr | 5 | 1 | + 1 | + 6 | − 1 | (−49) |
| γ 24521 | 30 | 0633 | 3 | 2 | tr | 5 | tr | + 4 | (+ 8) | (− 6) | ..... |
| γ 24526 | Oct. 1 | 0634 | 3 | 2 | 1 | 5 | 0 | + 3 | (+11) | + 2 | ..... |
| γ 24531 | 2 | 0635 | 3 | 2 | tr | 5 | 0 | + 4 | + 8 | + 3 | ..... |
| γ 24537‖ | 3 | 0636 | (3) | (2) | tr | (5) | tr | + 5 | ..... | (+ 7) | ..... |
| γ 24542 | 4 | 0637 | 3 | 2 | tr | 5 | tr | + 5 | + 8 | + 5 | (−37) |
| γ 24552 | 16 | 0649 | 5 | 2 | tr | 6 | 7 | + 8 | + 6 | + 2 | −21 |
| E 635 | 22 | 0655 | 4 | 3 | tr | 6 | 7 | + 5 | + 6 | + 3 | −27 |
| γ 24643 | 30 | 0663 | 4 | 2 | tr | 6 | 6 | + 4 | +10 | + 2 | −22 |
| γ 24656 | Nov. 1 | 0665 | 3 | 2 | 1 | 7 | 3 | + 4 | (+ 1) | + 6 | −34 |
| γ 24662 | 2 | 0666 | 4 | 3 | 1 | 8 | 1 | + 5 | +11 | + 6 | −31 |
| γ 25196 | 1943 July 8 | 0914 | 3 | 0 | 3 | 8 | 0 | +23 | (+27) | ..... | ..... |
| E 909 | Aug. 11 | 0948 | 3 | 0 | 2 | 8 | 1 | +10 | (+15) | ..... | +14 |
| E 913 | 12 | 0949 | 3 | 0 | 2 | 8 | 4 | + 8 | +10 | ..... | +19 |

* Dispersion at $H\gamma$ in A/mm: γ plates, 78; C, 40; E, 66.

† Includes visual region.

‡ JD 2430128.

§ Weak exposure.

‖ Double spectrum.

Humason and I examined the region with the 100-inch telescope. The only bright-line object we could find was BF Cyg itself.[7] Its spectrum, photographed that night by Mr. Humason, showed a dozen bright hydrogen lines, as well as numerous bright lines of

[6] *Pub. A.S.P.*, **52**, 335, 1940.

[7] The mystery of the temporary bright line observed by Mr. Miller has not yet been solved.

other elements. Spectrograms with higher dispersion taken by the writer during the following month brought out a rich bright-line spectrum with numerous forbidden lines, some of which underwent remarkably quick changes in intensity. Similar changes were again observed in 1941, 1942, and 1943.

TABLE 2

BRIGHT LINES ON PLATE γ24455, SEPTEMBER 18, 1942

| λ | Int. | Ident. | λ | Int. | Ident. |
|---|---|---|---|---|---|
| 3835* | 6 | $H\eta$ | 4359 | tr | [Fe II] |
| 3856 | 2 | Si II | 4363 | 4 | [O III] |
| 3863 | 1 | Si II | 4385 | 1 | Fe II |
| 3869 | 3 | [Ne III] | 4388 | 1 | He I |
| 3889 | 10 | $H\zeta$, He I | 4414 | tr | [Fe II] |
| 3900 | tr | Ti II | 4417 | 1 | Fe II, [Fe II] |
| 3906 | 1 | Si I | 4471 | 6 | He I |
| 3914 | 1 | Fe II | 4489 | 1 | Fe II |
| 3930 | 1 | Fe II | 4491 | 1 | Fe II |
| 3934 | 1 | Ca II | 4508 | 1 | Fe II |
| 3938 | 2 | Fe II | 4515 | 1 | Fe II |
| 3945 | 1 | Fe II | 4520 | 1 | Fe II |
| 3965 | 3 | He I | 4523 | tr | Fe II |
| 3968 | tr | [Ne III] | 4534 | tr | Fe II, Ti II |
| 3970 | 15 | $H\epsilon$ | 4542 | tr | Fe II |
| 3974 | tr | [Fe II] | 4549 | 2 | Fe II, Ti II |
| 4026 | 2 | He I | 4556 | 2 | Fe II |
| 4068 | tr | [S II] | 4576 | tr | Fe II |
| 4076 | tr | [S II] | 4584 | 3 | Fe II |
| 4102 | 20 | $H\delta$ | 4607 | 1 | [Fe III] |
| 4121 | tr | He I | 4620 | tr | Fe II |
| 4123 | tr | Fe II | 4629 | 4 | Fe II |
| 4128 | tr | Si II | 4641 | tr | N III |
| 4144 | 1 | He I | 4651 | tr | C III |
| 4173 | 2 | Fe II | 4658 | 10 | [Fe III] |
| 4178 | 1 | —, [Fe II] | 4686 | tr | He II |
| 4179 | 3 | Fe II | 4702 | 5 | [Fe III] |
| 4233 | 4 | Fe II | 4713 | 2 | He I |
| 4244 | tr | [Fe II] | 4734 | 2 | [Fe III] |
| 4267 | tr | C II | 4755 | 1 | [Fe III] |
| 4277 | tr | [Fe II] | 4769 | 1 | [Fe III] |
| 4287 | 1 | [Fe II] | 4861 | 50 | $H\beta$ |
| 4297 | 1 | Fe II | 4923 | 3 | He I, Fe II |
| 4303 | tr | Fe II | 4959 | 3 | [O III] |
| 4314 | tr | Ti II | 5007 | 8 | [O III] |
| 4341 | 30 | $H\gamma$ | 5017 | 3 | He I, Fe II |
| 4352 | 2 | Fe II | | | |

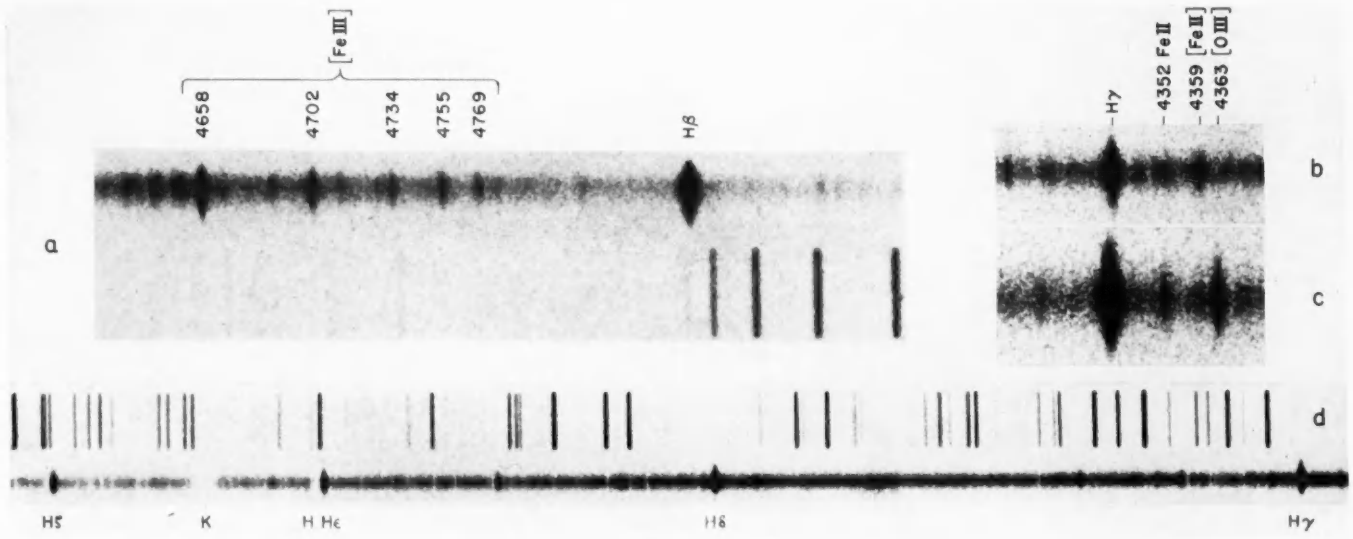
* About a dozen *H* lines of shorter wave length than $H\eta$ are recorded on this plate.

Miss Cannon and Mrs. Mayall found a distinct variation in the intensity of the bright hydrogen lines on seven Harvard objective-prism spectrograms:

When the star was brightest, as on November 1, 1898, the spectrum was almost continuous, with only a suspicion of bright and dark lines. When faintest, as on June 7, 1924, and August 26, 1932, $H\gamma$ and $H\delta$ were distinct emission lines, as also at median brightness on August 14, 1922. Other faint emission lines were seen. On August 12 and 14, 1922, and August 17, 1923, $H\beta$ was bright. Because of the small dispersion, the nebular line λ 4363 is not clearly separated from $H\gamma$.[8]

[8] *Harv. Announcement Cards*, No. 536, 1940.

PLATE XXII




Spectrograms of BF Cygni

*a*) E 236 Aug. 31, 1941; *b*) E 212 Aug. 6 1941; *c*) E 579 Sept. 15 1942; *d*) E 909, Aug. 11 1943

The spectrograms on which the present study is based are listed in Table 1. The generous assistance of several colleagues, especially in obtaining the 1942 series, is gratefully acknowledged.

Tables 2 and 3 list the bright lines measured. All the lines vary in intensity; but, because the plates differ in emulsion, effective exposure, and other observational details, it is not possible to give a complete account of the changes, the data on some of the weaker lines being fragmentary. The changes, however, are unmistakable, many of them indeed being conspicuous. (See Plate XXII.)

TABLE 3

ADDITIONAL BRIGHT LINES

| λ | Ident. | λ | Ident. |
|---|---|---|---|
| 3722 | [*S* III], $H\mu$ | 4568 | *Si* III |
| 3783 | *Fe* II | 4574 | [*Fe* III], *Si* III |
| 3807 | *Si* III? | 4634 | *N* III |
| 3820 | *He* I | 4666 | [*Fe* III], *Fe* II |
| 3825 | *Fe* II | 4728 | [*Fe* II] |
| 3829 | *Mg* I | 4775 | [*Fe* II] |
| 3832 | *Mg* I | 4778 | [*Fe* III] |
| 3838 | *Mg* I | 4814 | [*Fe* II], [*Fe* III] |
| 3848 | *Mg* II | 5011 | [*Fe* III] |
| 3850 | *Mg* II | 5041 | *Si* II |
| 3926 | *He* I | 5056 | *Si* II |
| 3995 | *N* II | 5058 | [*Fe* II] |
| 4009 | *He* I | 5069 | *Fe* II |
| 4089 | *Si* IV | 5097 | *Fe* II |
| 4097 | *N* III | 5235 | *Fe* II |
| 4116 | *Si* IV | 5262 | [*Fe* II], *Fe* II |
| 4200 | *N* III | 5270 | [*Fe* III] |
| 4258 | *Fe* II | 5276 | *Fe* II |
| 4267 | *C* II | 5317 | *Fe* II |
| 4290 | *Ti* II | 5363 | *Fe* II |
| 4300 | *Ti* II? | 5535 | *Fe* II |
| 4314 | *Ti* II? | 5755 | [*N* II] |
| 4320 | [*Fe* II] | 5876 | *He* I |
| 4327* | ? | 6247 | *Fe* II |
| 4368 | *Fe* II, *Ti* II | 6316 | *Fe* II? |
| 4400 | *Ti* II | 6347 | *Si* II |
| 4447 | *N* II | 6384 | *Fe* II? |
| 4452 | [*Fe* II] | 6456 | *Fe* II |
| 4458 | [*Fe* II] | 6563 | $H\alpha$ |
| 4481 | *Mg* II | 6678 | *He* I |
| 4553 | *Si* III | | |

* Normal wave length probably about 4326.6.

Table 1 indicates the relative intensities of the bright lines of helium, iron, and oxygen. For plate $\gamma$ 24455, chosen as a standard, the values correspond roughly to the relative intensities of the strongest lines of the various atoms or ions. For the other plates the intensities were estimated by comparison on the spectrocomparator with $\gamma$ 24455. The individual lines measured on $\gamma$ 24455 are listed in Table 2; additional lines measured on other plates appear in Table 3.

*Hydrogen.*—On all the Mount Wilson spectrograms the bright hydrogen lines are very intense; on most plates the decrement toward the head of the series appears to be relatively slow. Thus, on most of the plates fifteen to twenty lines, beginning with $H\beta$, were measured; on $\gamma$ 22932 the series is visible at least to *H* 29, λ 3663.

Intercomparison of plates shows that changes of intensity and decrement occur. The lines are relatively strong on $\gamma$ 22932, $\gamma$ 24476, $\gamma$ 24481; relatively weak on $\gamma$ 23074,

$\gamma$ 23876, $\gamma$ 25196, E 909, and E 913. To some extent the intensities of lines of other elements appear to behave like those of hydrogen. Exceptions to this tendency may, however, be striking; for example, radical changes in the intensities of the nebular lines may be accompanied by little or no change in the Balmer lines.

Blending of the *He* I line $\lambda$ 3888.65 with $H\zeta$, $\lambda$ 3889.05, is evidenced by the systematic displacement of $H\zeta$ (about $-10$ km/sec) with respect to the other $H$ lines. Another Balmer line sometimes blended is $H\mu$, $\lambda$ 3721.94, which also has a mean relative displacement of about $-10$ km/sec. On those plates with the larger displacements (ranging up to $-20$ km/sec) $H\mu$ has an apparent intensity obviously too great for its position in the Balmer series; in fact, it appears that at times the blending line may be as strong as $H\mu$ itself.[9] If the line has the same displacement as the $H$ lines, its normal wave length must be about 3721.6; if the displacement is that of the nebular lines, the wave length would be somewhat greater, perhaps 3722.1, a value close to that of the auroral-type line of [*S* III]. This identification is strengthened by the fact that the intensity appears to vary in about the same manner as that of the lines of [*O* III]. The identification would be confirmed by the presence of the nebular-type line of [*S* III], $\lambda$ 6311, on spectrograms of BF Cyg taken when the [*O* III] lines are strong. Unfortunately, no suitable plate has been obtained.

*Helium.*—The intensities of the bright lines of *He* I, indicated in Table 1, tend to follow those of the nebular line $\lambda$ 4363, but the changes are not nearly so great and there are some discrepancies. The singlet lines are relatively weak with respect to the triplets, presumably indicating a rather high pressure in the stratum where they originate. In the spectra of AX Per, RW Hya, and CI Cyg the singlets are relatively much stronger.

The line $\lambda$ 4686 *He* II, frequently present, is never strong. Its changing intensity is probably paralleled by that of the lines of *C* III, *N* III, and *Si* IV.

*Iron.*—Bright lines of *Fe* II[10] were strong in 1940, weak or absent in 1941 and 1943, and of intermediate intensity in 1942. (See Table 1.) The behavior of the forbidden lines [*Fe* II] was quite different: they were strong in 1941, weak in 1942, intermediate in 1940 and 1943. Lines of [*S* II] $\lambda$ 4068, $\lambda$ 4076 behaved like those of [*Fe* II]. Lines of [*Fe* III], outstanding on all plates except those of 1940, are stronger relatively to the continuous background than in any other stellar spectrum yet observed. (See Plate XXII.) At least nine lines of the $^5D-{}^3F$ multiplet are present. Iron lines of higher stages of ionization have not been found.

*Nebular lines.*—Perhaps the most surprising phenomena observed in this unusual spectrum are the rapid changes in intensity to which the nebular lines are subject (Table 1). These changes are larger and take place more quickly than those of other strong lines. The nebular line best observed is $\lambda$ 4363 [*O* III]; but the changes of $\lambda$ 4959, $\lambda$ 5007 [*O* III] and $\lambda$ 3869, $\lambda$ 3968 [*Ne* III] are parallel and equally striking. Marked changes sometimes occur within 24 hours. The data for 1942 are plotted in Figure 1.

*Absorption spectrum.*—Although a fairly strong continuous spectrum is present on nearly all the plates, dark lines are not ordinarily in evidence. A late-type absorption spectrum, however, is visible on several plates taken in 1941, being especially well marked on E 188. On this plate the dark lines and bands correspond to type gM4. The radial velocity from nine dark lines is $+1$ km/sec. On the next plate, E 212 taken 35 days later, the absorption features appear to be weakened by superposed continuous spectrum. On E 231, 24 days later, the M-type lines are scarcely visible; but narrow displaced dark lines (radial velocity $-31$ km/sec) are present at H and K. On several plates taken at this time the stronger helium lines have weak dark companions on their violet

[9] A similar strengthening of $H\mu$ in the spectra of planetary nebulae, reported by Bowen and Wyse, *Lick Obs. Bull.*, **19**, 1, 1939, was attributed by them to a line of [*S* III].

[10] A convenient list of multiplets of *Fe* II with their intensities in BF Cyg, in July, 1942 was published by Swings and Struve, *Ap. J.*, **97**, 194, 1943.

sides. Thus BF Cyg, like Z And and T CrB, seems to have had a temporary expanding shell, although not strongly developed.

The M-type lines are not seen on the 1942 plates; nor are the displaced dark lines, except a weak narrow component on the short-wave-length side of $H\zeta$ which is probably connected with the blended *He* I line. The absorption spectrum is again well marked on plates E 909 and E 913 taken in August, 1943, the type appearing slightly earlier than in 1941. The radial velocity from twenty-five lines (thirteen with low weight), +5 km/sec, agrees within errors with the value +1 km/sec obtained in 1941. Several bright helium lines are accompanied by displaced dark companions as in 1941.

The appearances of the M-type spectrum were not accompanied by appreciable changes in the visual magnitude; this circumstance is difficult to explain.

*Displacements.*—The displacements of the bright lines of various elements are tabulated for individual plates in Table 1 and by years in Table 4. These data are based on two measurements of each plate—one by Miss Cora G. Burwell, one by the writer. It is obvious that various elements yield substantially different velocities, that several elements show changes from year to year, and that the relative displacements are not always the same. Except possibly in *He* I, the measurements show that quick changes, if present, are small. Changes from year to year, however, may be considerable.

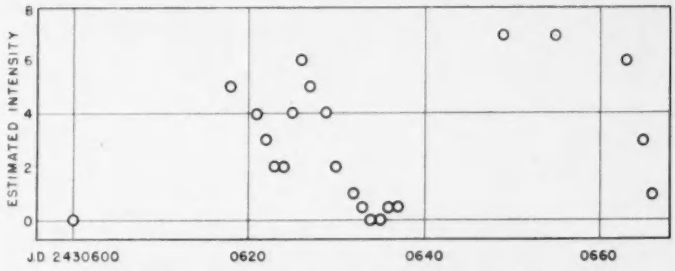



FIG. 1—Intensities of nebular lines in 1942

The hydrogen lines yielded the same velocity in 1940, 1941, and 1943, but a decidedly different one in 1942, although in any one year the range was small. The helium lines behave differently: the means for 1940, 1941, and 1942 do not differ significantly, but in 1940 and 1941 there was a considerable range, the plates upon which the *He* I lines were relatively weak yielding algebraically large displacements. In 1942 the range in velocity and in intensity was small. Lines of *Fe* II yielded the same velocity in 1940 and 1942, a slightly different one in 1941. So far as may be determined, velocities from lines of [*Fe* II] and of *Si* II are similar to those from lines of *Fe* II. Velocities from lines of [*Fe* III] are algebraically negative with respect to those of *Fe* II and [*Fe* II]. They appear to correspond more nearly to the velocities from the nebular lines.

Displacements of [*Ne* III] λ 3869, λ 3968 and of [*O* III] λ 4959, λ 5007 probably agree within errors of measurement with those of [*O* III] λ 4363. In 1941 and again in 1943 the mean velocity from these nebular lines agreed approximately with that from *H* lines; but in 1940 the residual was −42 km/sec, in 1942, −35 km/sec. These changes may possibly be connected with the period of 754 days in the total light found by Jacchia. The quick changes in the intensities of the nebular lines do not seem to be reflected in the displacements.

Not many generalizations can be drawn with certainty from the present data. Both the intensities and the displacements of the bright lines are evidently subject to complex changes. The relationships indicated in Table 5 may be significant.

*Discussion.*—This strange object clearly belongs in the group of stars with "combination" spectra along with Z And, AX Per, CI Cyg, and AG Peg. Its peculiarities, differ-

ing in degree, rather than in kind, from those of the other stars, may help elucidate the physical phenomena which produce these abnormal spectra. The bright lines of BF Cyg undergo complex changes in intensity and displacement which suggest the action of exciting radiation, probably variable, on a stratified, pulsating atmosphere. A tendency toward emission, shared by atoms of a dozen elements in various stages of ionization, is evidently governed by a common cause. The general brightness of the incandescent atmosphere is subject to fluctuations which probably reflect changes in the intensity of radiation from a particular source. But the behavior of the nebular lines points to some

TABLE 4

YEARLY MEANS OF DISPLACEMENTS OF BRIGHT LINES
(Km/Sec)

| YEAR | APPROX. MEAN JULIAN DAY | *H* | *He* I | *Si* II | *Fe* II | [*Fe* II] | [*Fe* III] | [*Ne* III] | [*O* III] | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | λ 4363 | λ 4959 λ 5007 |
| 1940..... | 2429896 | +19 | +11 | +2 | + 3 | +2 | −21 | (−34) | −22 | −28 |
| 1941..... | 2430199 | +22 | +12 | (−4) | −10 | (−4) | − 4 | ..... | +22 | (+19) |
| 1942..... | 2430634 | + 4 | + 7 | +5 | + 4 | +4 | −16 | −35 | −30 | −32 |
| 1943..... | 2430937 | +14 | (+16) | ..... | ..... | −9 | +13 | (+18) | +17 | (+29) |

TABLE 5

RADIAL VELOCITIES OF GROUPS OF LINES

| Group | Description | Element | Mean Velocity | Amplitude |
|---|---|---|---|---|
| I..... | Dark | Metals | + 3 km/sec | ? |
| II..... | Bright | *Fe* II, [*Fe* II], *Si* II | + 1 | Small |
| III..... | Bright | *H* | +14 | 18 km/sec |
| | | *He* I | +11 | 9 |
| IV..... | Bright | [*O* III], [*Ne* III], [*Fe* III] | − 4 | 50 |

physical circumstance which is highly selective in its effect. Thus there appears to be a specific, as well as a general, cause of line emission, although the two may not be independent.

The exact nature of these sources of excitation is not clear. The rapidity of the changes of the lines of [*O* III] and [*Ne* III] and the constant, or nearly constant, relative intensity of λ 4363 and λ 5007 argue against changes in the density of the emitting oxygen and neon. The facts do not suggest jets of nebular material, as in R Aqr. Whatever may be the process (recombination?) responsible for the emission of *H*, *He*, *Mg*, *Si*, *Fe*, etc., it seems probable that the quick changes of [*O* III] and [*Ne* III] are under the immediate control of some special type of radiation which is turned on or off at intervals. This interesting problem, like the wider one of the general interpretation of combination spectra, may perhaps best be approached through the comparative study of several stars. Such studies will become increasingly effective as additional observations accumulate.

# PARABOLIZING MIRRORS WITHOUT A FLAT

FRANK E. ROSS
California Institute of Technology
*Received July 6, 1943*

ABSTRACT

Through the device of inserting a suitably designed simple lens or spherical mirror near the center of curvature of a spherical mirror which is to be parabolized, the operation of parabolizing can be carried on conveniently without the use of the customary auxiliary flat. In nearly all cases sufficiently perfect parabolization results. In the exceptional case of the 200-inch mirror for the Mount Palomar Observatory, it is found impossible fully to correct in this way, necessitating the use of an auxiliary correcting plate in conjunction with lens or mirror.

The possibility of testing a parabolic mirror at its center of curvature through the interposition of a small auxiliary spherical mirror or a simple positive lens was brought to my attention by Dr. John A. Anderson, who had in mind its application to the problem of parabolizing the 200-inch mirror. If feasible, the use of the 120-inch flat for the parabolizing could be dispensed with—a saving of no little importance. So far as I know, the optics of such a system, which can be called a "compensating" system, has not been completely worked out. Again, so far as I know, the first suggestion for the use of such a system came from F. J. Hargreaves.[1] I quote: "He [the author] was reminded by Mr. Burch of ideas he had long had in mind for making use of the spherical aberration of a lens in testing parabolic mirrors at the center of curvature." And C. R. Burch[2] appears to have applied the idea and has given some rough calculations of such a system. It is curious to note that these ideas, of the greatest importance in themselves, were brought out in a casual discussion of a paper by Burch, "Compensation of Spherical Aberration in Telescopes."[2]

The optical system, for the two cases of a compensating spherical mirror $M$ and a lens $Q$, is shown in Figure 1. $C$ is the center of curvature of the parabola ($y = 0$). For a mirror-compensating system the mirror is placed beyond $C$. For a lens system the lens is placed between $C$ and the mirror. The light-source is at $L$. The lens system has the disadvantage that the testing light must be monochromatic. It is seen that $C$ and $L$ must be conjugate foci for the axial pencils. Application will be made at once to the case of the 200-inch mirror.

Let $\alpha$ be the angle made with the axis by the outgoing ray from $L$, which strikes the parabola at its outer zone ($y = 100$) and intersects the axis at the point $E$. If this ray meets the parabola normally, it will return along its outgoing path, finally passing through its origin $L$. It is obvious that the center of the mirror returns the light to $L$, since $L$ and $C$ are conjugate foci. It is seen that $EC$ is the spherical aberration of $M$ or $Q$ and that our problem is so to design the compensating system that $EC$ is equal to the displacement of the normal to the parabolic mirror along its axis, this displacement being given by

$$EC = \frac{y^2}{2R}, \tag{1}$$

where $R$ is the radius of curvature of the mirror. Taking $y = 100$ and $R = 1332$, we have $EC = 3.754$ inches.

Stating the problem in a different way, $M$ or $Q$ must be so designed that $\alpha = N$, where $N$ is the angle made with the axis by the normal to the parabola at $y$, given by

$$\tan N = \frac{y}{R}. \tag{2}$$

[1] *Brit. Astr. Assoc. Jour.*, **48**, 99, 1937–38.

[2] *Ibid.*, p. 100.

CASE I. MIRROR SYSTEM

Let $S$ be the longitudinal spherical aberration, due to $M$, of a ray reflected by $M$ at a height $h$, the focal length of the mirror being $F$ and the conjugate focal distances, $s$ and $s'$, where $s = UL$ and $s' = UC$. Third-order theory gives at once

$$S = \tfrac{1}{8} h^2 \frac{(s' - 2F)^2}{F^3}. \tag{3}$$

Applying this equation to the outer zone $y = 100$, putting in a first approximation to $h$, and equating to $EC$ given by equation (1), we have

$$\left.\begin{aligned} h &= \tfrac{100}{1382}\, s', \\ S &= 3.754\ . \end{aligned}\right\} \tag{4}$$

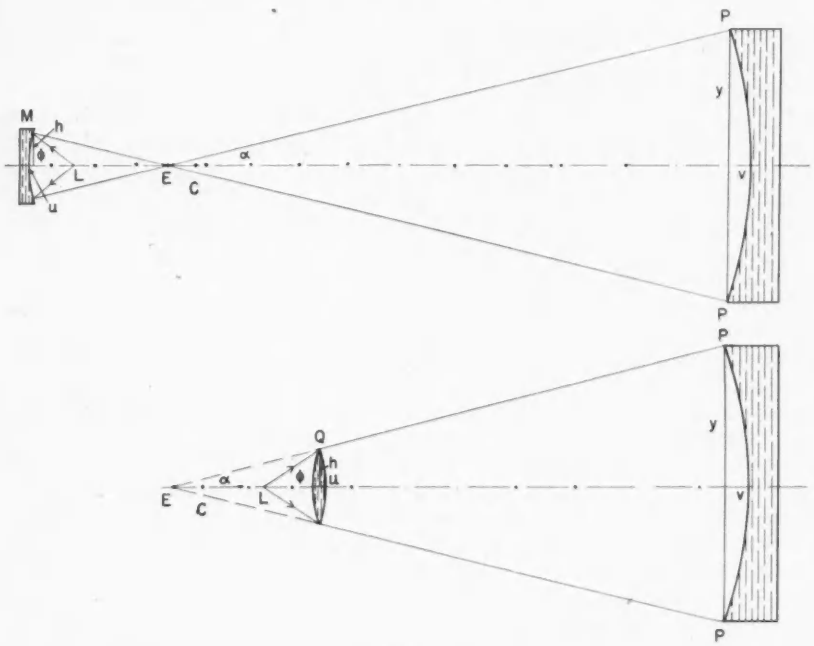



FIG. 1

Hence for a spherical mirror of assigned focal length $F$, the distance $s'$ is determined, and conversely. It will be shown later that $s'$ should be as large as possible, being governed by the diameter $D$ of the available mirror $M$. Having assigned $D$, and therefore $s'$, we have $F$ from equation (4), and $s$ follows simply. The value thus found for $F$ is only a first approximation. Its exact value must be found by successive approximations, through ray tracings. In Table 1 will be found final values of $F$ and $s$ for two chosen cases, $s' = 60.0$ and 180.0.

Having thus adjusted the outer zone confocal with the central zone, it remains to examine the intermediate zones. As in any lens system, it is to be expected that they will give deviations from the focal point $L$ determined by the outer and central zones. The computation has been made for a number of values of $y$, with results given in Table 1. Tabulation has been made in the form $\Delta N$, where

$$\Delta N = a - N \tag{5}$$

It is seen that the sign of $\Delta N$ is negative, which means that the parabola will be overcorrected. The corresponding values of the circle of confusion are given on page 345. The increase in efficiency with increasing $s'$ and $D$ is noteworthy, the relation being closely linear with $s'$.

A disadvantage of the mirror system is the large value of the angle of view, $2\phi$, as compared with a lens-compensating system. A further disadvantage is its relative inconvenience of operation.

TABLE 1

MIRROR SYSTEM

(Solution for Two Values of $s'$)

| $s'$ | 60.0 | 180.0 |
|---|---|---|
| $s$ | 11.463 | 49.494 |
| $F$ | 9.624 | 38.820 |
| $D$ | 8.4 | 26.3 |
| $2\phi$ | 41°68 | 30.38° |

| $y$ | $\Delta N$ $S'=60.0$ | $\Delta N$ $S'=180.0$ | $y$ | $\Delta N$ $S'=60.0$ | $\Delta N$ $S'=180.0$ |
|---|---|---|---|---|---|
| 0 | 0.00 | 0.00 | 60 | −1.40 | −0.56 |
| 10 | −0.04 | − .01 | 70 | 1.69 | .66 |
| 20 | 0.09 | .04 | 80 | 1.68 | .66 |
| 30 | 0.28 | .10 | 90 | −1.22 | − .51 |
| 40 | 0.63 | .19 | 100 | 0.00 | 0.00 |
| 50 | −1.05 | −0.37 | | | |

CASE II. LENS SYSTEM

The case of a lens-compensating system ($Q$, Fig. 1) differs from that of the mirror system in that the spherical aberration is not wholly determined by $s'$ and $F$ (eq. [3]) but by an additional parameter $\sigma$, the shape-factor of the lens, defined by

$$\sigma = \frac{R'+R}{R'-R}, \tag{6}$$

$R$ and $R'$ being the first and second radii, respectively. The longitudinal spherical aberration $S$, for the zone at height $h$, is given by the following set of equations, in which $n$ is the index of refraction:

$$\left.\begin{aligned} &\frac{1}{F} = \frac{1}{s'} - \frac{1}{s}, \\ &\pi = \frac{s'+s}{s'-s}, \\ &A = \frac{n+2}{n(n-1)^2}\sigma^2 + \frac{4(n+1)}{n(n-1)}\pi\sigma + \frac{3n+2}{n}\pi^2 + \frac{n^2}{(n-1)^2}, \\ &K = \tfrac{1}{8}h^2 s'^2, \\ &h = \tfrac{100}{1332}s', \qquad \text{(first approx.)} \\ &S = \frac{KA}{F^3}. \end{aligned}\right\} \tag{7}$$

Equating $S$ to 3.754, as in the case of the mirror system, leads to a quadratic for $\sigma$, whence the radii can be computed. The final values are obtained by ray tracing, trial and error, making $\Delta N$ strictly zero for $y = 100$. The values of $\Delta N$ for intermediate zones are then to be computed by ray tracing. It is to be noted that in the above equations there is an additional free parameter, $s$. The question arises: Is there an optimal value of $s$, which, for any given $s'$, leads to a set of minimum values of $\Delta N$? In order to determine this, solutions have been made, with $s' = 60.8$, and varying $s$ within reasonable limits. The results are shown in Table 2. The probable computational

TABLE 2

DEPENDENCE OF $\Delta N$ ON $s$ ($s' = 60.8$)

| $s$ | 17.5 | 20.5 | 23.5 | 26.5 | 29.5 | 32.5 | 35.5 |
|---|---|---|---|---|---|---|---|
| $F$ | 24.57 | 30.90 | 38.32 | 46.95 | 57.30 | 69.83 | 85.30 |
| Final $\sigma$ | Imag. | − 0.87 | − 0.45 | − 0.03 | + 0.50 | + 1.18 | + 2.13 |
| $2\phi$ | ..... | 26°9 | 23°2 | 20°6 | 18°6 | 16°8 | 15°4 |
| $\Delta N(y = 76)$ | ..... | + 1".69 | + 1".48 | + 1".52 | + 1".49 | + 1".61 | + 1".67 |

error of $\Delta N$ is roughly 0.04". Table 2 shows that for a given value of $s'$, there is nothing to choose from between the limits of 23.5 and 29.5 for $s$, in so far as $\Delta N$ is concerned. However, the larger values of $s$ give a smaller angle of view, which is an advantage in viewing the mirror. It will be noted that the sign of $\Delta N$ is positive, which means an undercorrected mirror.

In order to verify the dependence of $\Delta N$ on $s'$ for a lens-system $Q$, a dependence already found for the mirror system, two additional cases will be chosen, $s' = 30.0$ and $s' = 120.0$, taking $s$ equal to one-half of $s'$ in each case. The results are given in Table 3.

TABLE 3

DEPENDENCE OF $\Delta N$ ON $s'$

| $s'$ | 30.0 | 120.0 | $s'$ | 30.0 | 120.0 |
|---|---|---|---|---|---|
| $s$ | 15.0 | 60.0 | $D$ | 5.0 | 20.0 |
| Final $\sigma$ | + 1.48 | − 0.22 | $\Delta N(y = 76)$ | + 3".26 | + 0".69 |
| $2\phi$ | 19°0 | 17°7 | | | |

$\Delta N$ has been computed for a value of $y$ which gives a maximum. These results are in harmony with those obtained for a mirror system and show that it is highly advantageous to choose $s'$ as large as is practicable, governed by the size of the lens which is available.

For the parabolizing of the 200-inch mirror, it was decided to use a lens-compensating system. This has the double advantage of being convenient in operation and of leaving an undercorrected parabola. Fortunately, a very fine 10-inch disk of Schott borosilicate crown was available, which was pressed into service. The computations were carefully made, with the following results:

$$R_1 = +70.800\,, \quad R_2 = -28.551\,, \quad t = 0.800\,, \quad 2\phi = 22°9\,,$$
$$s = 23.500\,, \quad s' = 60.028 \quad \text{(both measured from } R_1\text{)}.$$

The values of $\Delta N$ were found to be closely identical with those in Table 1, for $s' = 60.0$. The edge, $y = 100$, was left slightly undercorrected, for the sake of the corrector plate, in which $dx/dh$ should not become zero or change sign.

Before going on to the next step, namely, the computation of a corrector plate to take up the outstanding errors of $\Delta N$, it will be of interest to compute the size of the confusion disk, assuming that correction is made only through use of $M$ or $Q$. If the 200-inch disk is left spherical, I find that the confusion disk would be 30″ (2.5 mm) in diameter. Making use of a 10-inch mirror or lens, the confusion disk is reduced to 3.2″. With a 30-inch mirror the correction would be quite good, the confusion disk being only 1.0″ in diameter, which is of the order of magnitude of the atmospheric confusion disk. I have computed the degree of compensation which would be obtained by the use of a 10-inch lens in parabolizing the Mount Wilson 100-inch mirror and find it to be very high, the confusion disk in this case being only 0.22″ in diameter, sufficiently small to be taken as final.

*Corrector plate.*—With the adopted 10-inch compensating lens described above, it is seen that compensation is not sufficiently complete and that an auxiliary correcting plate will be necessary. A convenient place for this is between lens and mirror, at a distance of 0.10 inch from $R_2$; the plate should have a thickness of 0.25 inches. The distance $s$ will be unchanged, but $s'$ must be reduced to 59.943 inches. The basic principle in its computation is simple, but its application is laborious. The first surface of the plate is assumed to be flat, and all the correction is placed on the second surface $S_2$. A number of rays are traced through the lens and the first surface of the plate. From this point it is a case of trial and error for each ray, namely, finding the inclination to the axis of the normal to the surface $S_2$ which will send the ray in a direction normal to the parabola at its point of impingence. A sufficient number of rays must be chosen so that an accurate graphical relation between slope and distance $h$ from the axis may be obtained. Finally, a process of numerical integration will give the co-ordinates of $S_2$. The results are to be found in Table 4, for $y = 100$, $h = 4.87$ inches. The unit of $x$ is 0.001 mm.

TABLE 4

CO-ORDINATES OF SECOND SURFACE OF CORRECTOR PLATE

| $h$ | $x$ | $h$ | $x$ | $h$ | $x$ | $h$ | $x$ | $h$ | $x$ |
|---|---|---|---|---|---|---|---|---|---|
| (Inches) | | (Inches) | | (Inches) | | (Inches) | | (Inches) | |
| 0.1 | 0.00 | 1.1 | 0.15 | 2.1 | 1.65 | 3.1 | 6.32 | 4.1 | 13.73 |
| 0.2 | 0.01 | 1.2 | 0.21 | 2.2 | 1.96 | 3.2 | 6.99 | 4.2 | 14.45 |
| 0.3 | 0.01 | 1.3 | 0.28 | 2.3 | 2.30 | 3.3 | 7.69 | 4.3 | 15.14 |
| 0.4 | 0.01 | 1.4 | 0.37 | 2.4 | 2.67 | 3.4 | 8.41 | 4.4 | 15.79 |
| 0.5 | 0.02 | 1.5 | 0.48 | 2.5 | 3.08 | 3.5 | 9.13 | 4.5 | 16.38 |
| 0.6 | 0.03 | 1.6 | 0.61 | 2.6 | 3.52 | 3.6 | 9.91 | 4.6 | 16.90 |
| 0.7 | 0.04 | 1.7 | 0.76 | 2.7 | 4.00 | 3.7 | 10.68 | 4.7 | 17.34 |
| 0.8 | 0.06 | 1.8 | 0.94 | 2.8 | 4.53 | 3.8 | 11.46 | 4.8 | 17.66 |
| 0.9 | 0.08 | 1.9 | 1.14 | 2.9 | 5.08 | 3.9 | 12.23 | 4.9 | 17.86 |
| 1.0 | 0.11 | 2.0 | 1.38 | 3.0 | 5.68 | 4.0 | 12.99 | 5.0 | 17.94 |

*Optical arrangement for viewing mirror while parabolizing.*—It is perhaps needless to point out the great advantage of being able to view the mirror in its entirety while parabolizing, as against the standard method of using a flat, where only a portion of the surface can be seen at any one time. Two convenient arrangements may be adopted: (*a*) with pinhole light-source and cut-off on opposite sides of the axis and as near as practicable; (*b*) sending in light from the side, reflecting it to the 200-inch mirror by means of a half-silvered plane plate, set at an angle of 45°, and viewing the returning beam through the plate. This method has the obvious advantage over (*a*) of working precisely on the axis. It has the disadvantage, however, of introducing aberrations in the transmitted beam, such as spherical aberration, coma, and astigmatism, the last two being more serious and prohibitive for ordinary glass thickness. Dr. Anderson has

overcome this difficulty by the use of a microscope cover glass having a thickness of 0.25 mm. for the plane plate. This is placed 20 mm in front of the focus of the returning beam. I have computed the optical aberrations of this setup and find them satisfactorily small. Assuming the source of light to be on the right as one looks toward the mirror, I find that the central ray is displaced 0.0685 mm to the left, while the extreme rays of the returning cone of light lying in the horizontal plane (angle of cone, $2\phi = 22.90°$), intersect at a point 0.0713 mm to the left, giving a comatic difference of 0.0028 mm, too small to be visible. The longitudinal astigmatism is found to be 0.014 mm, likewise beyond the limit of visibility.

# A SPECTROGRAPHIC STUDY OF THE TRIPLE SYSTEM IN 59 d SERPENTIS

ELIZABETH CORNWALL TILLEY
University of Michigan Observatory
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## ABSTRACT

In the visual double star 59 d Serpentis the primary component (5.4 mag.) is a triple system giving a composite spectrum of G0 and A2. The secondary component (7.8 mag.) is A0. Spectrograms of the triple system were taken at Yerkes Observatory in 1928–1929, at Ann Arbor in 1938–1942, and at Mount Wilson in 1941–1942. Velocities from these plates, combined with thirteen scattered observations in 1903–1909, yielded for the G-type star a period of 386.0 days. The following elements were derived: $\omega = 277°$, $K = 28$ km/sec, $\gamma = -23$ km/sec, $T = 221$ days, and $e = 0.47$.

For the orbit of the center of mass of the A-type binary system the above elements were adopted, except for $\omega = 97°$ and $K = 19$ km/sec.

A least-squares solution of the orbit of the A-type stars was made after the period of 1.8505205 days had been determined graphically from a composite plot of velocities in 1938–1942. The respective values of $K$ were 90 and 100 km/sec, $e$ was assumed to be zero, and $\gamma$ was also assumed to be zero, after the correction obtained in the solution was absorbed by revision of $K$ in the center-of-mass orbit.

On six plates an interstellar calcium line was measured between the components of the K line.

From a knowledge of $m \sin^3 i$, the ratio of the masses for the members of the triple system, and a dynamical parallax, approximate values were obtained for the masses and inclinations. The probable inclinations of the orbits preclude an eclipse of any components. The radii of the stars were also approximated.

Four low-dispersion spectrograms were taken of the faint visual companion. Velocities derived from these plates, relative to that of the center of mass of the triple system, suggest that this star might be a binary. A negligible change in the separation of 4″ has been observed during the past century.

## INTRODUCTION

Up to the present time comparatively little work has been done on individual composite spectra which were not those of two stars having orbital motion clearly indicated by the relative shift of the lines. The present problem is an investigation of the spectrum of 59 d Serpentis ($\alpha = 18^h22^m$, $\delta = +0°9'$, 1900), one of the stars included in Hynek's list of composite stars.[1] A visual double of apparent magnitudes 5.4 and 7.8, it has been observed occasionally since 1828. It is highly probable that the visual double is a physical pair. It shows a very slowly changing position angle and an almost negligible change in its separation of 4″. The common proper motion would be over 1″ in the interval of observation; and thus, if it were an optical double, a greater change in the position angle and separation would have been observed. In the *Henry Draper Catalogue* Miss Cannon designated the spectrum as composite—the brighter component of class A; the fainter, of class G. It was not clear at the time whether the composite character applied to the bright component alone or to the visual double. The secondary component of the visual pair (7.8 mag.) has a normal spectrum of class A0; and the primary component (5.4 mag.) is alone responsible for the composite spectrum A + G, as found by Leonard[2] in 1923 and by Hynek in 1938. The latter says that the composite spectrum "is not like that artificially produced by the superposition of two stars differing in photographic magnitude by nearly three magnitudes." This has been verified with spectrograms taken in Ann Arbor by the writer.

The triplicity of the primary component was discovered by Dean B. McLaughlin[3] in 1938, when he found that the K line of the A-type spectrum was distinctly double and

[1] *Contr. Perkins Obs.*, No. 10, 1938.

[2] *Lick Obs. Bull.*, **10**, 175, 1923.

[3] *Ap. J.*, **88**, 356, 1938.

showed a periodic variation repeated about every 2 days. At the same time R. Tremblot[4] found the same characteristic and stated that the period of this variation was 1.85 days. It is this triple star which is the subject of the present investigation, and it will be referred to as "d Serpentis."

## SOURCE AND REDUCTION OF MATERIAL

The majority of the spectrograms were taken at the Observatory of the University of Michigan during parts of the years 1938–1942, with the one- or two-prism spectrographs attached to the 37-inch reflector. They have a dispersion of approximately 40 A/mm at $H\gamma$. Dr. Otto Struve, of the Yerkes Observatory, kindly sent to the writer the fourteen plates taken in 1928–1929 on which he and Miss Johnson reported in 1939.[5] These plates, of dispersion approximately 26 A/mm at $H\gamma$, were remeasured at Ann Arbor in order

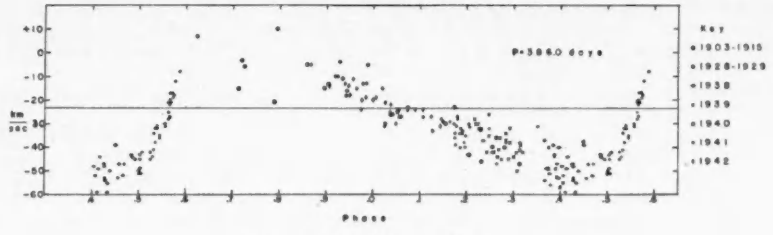



FIG. 1.—59 d Serpentis

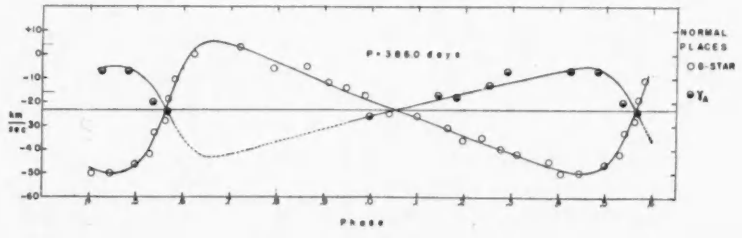



FIG. 2.—59 d Serpentis

that the same stellar and comparison lines might be used, so far as possible. Other spectrograms were taken with the 60-inch telescope at Mount Wilson, through the kindness of Dr. Walter S. Adams; and these fifteen plates supplemented those taken at Ann Arbor at the most significant phases observable in the velocity-curve of the G-type star. Their linear dispersion is approximately 36 A/mm at $H\gamma$. On many of these spectrograms which did not extend to the K line, owing to atmospheric conditions, the velocities of the A-type stars were found only from *Mg* II 4481, since a narrow slit on the spectrograph had been used.

The comparison spectra on the plates from the three observatories were either iron or titanium or a combination of the two. In order to have a homogeneous system, the same comparison lines were used as standards in all spectra of the same element, and the same stellar wave lengths were used in the Hartmann solutions for spectrograms with iron as with titanium spectra. Comparison lines were chosen for freedom from blending or broadening, their wave lengths being known with greater accuracy than those in the stellar spectrum.

The 1928–1929 plates from Yerkes Observatory were measured twice, and final velocities for the G-type star were derived using statistical methods, since some plates

[4] *C.R.*, **207**, 491, 1938.

[5] *Ap. J.*, **89**, 136, 1939.

were underexposed. From the majority of the plates taken in 1938 the final velocities are also the result of two sets of measures, made approximately a year apart. The difference between the two sets of measures amounted to not more than 10 per cent of the scatter within either set, and therefore the scatter is evidently inherent in the plates.

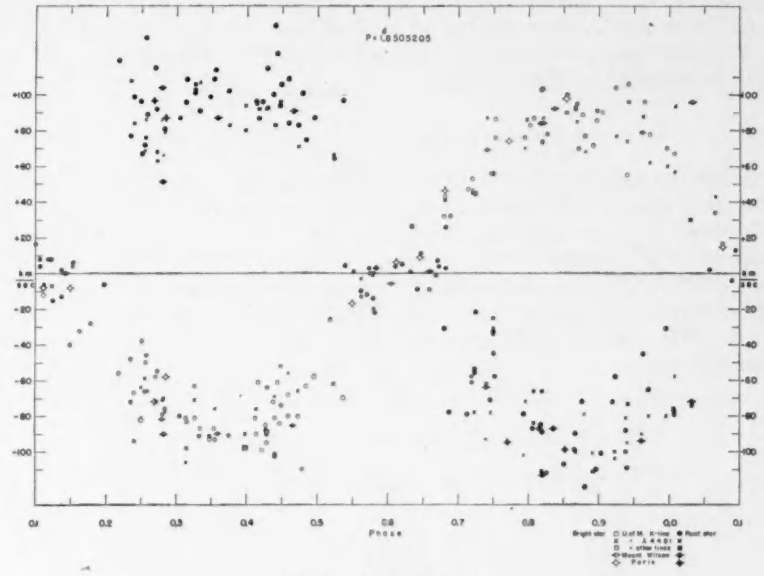



FIG. 3.—59 d Serpentis

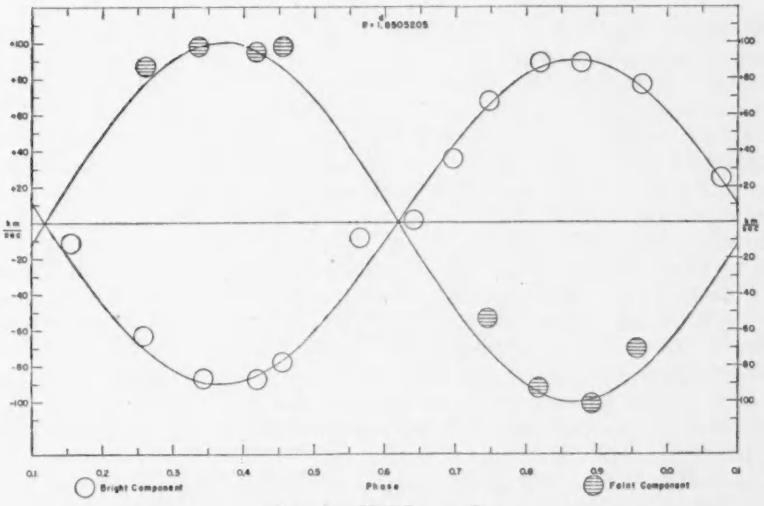



FIG. 4.—59 d Serpentis

All other spectrograms were measured once. The residuals of all individual plates are predominantly in the direction of the velocity of the stronger component of the K line. It therefore appears probable that much of the scatter is due to blending with lines of the stronger A-type spectrum. Some of the lines which are most noticeably affected are:

λ 4045 and λ 4063 of *Fe* I; λ 4215 of *Sr* II; λ 4227 of *Ca* I (asymmetry); λ 4233 of *Fe* II; and occasionally λ 4415 of *Fe* I.

Velocities of the A-type stars, as used in the computation of their orbits, depend on the K line of *Ca* II alone. However, some velocities were obtained also from the lines λ 4078 and λ 4215 of *Sr* II and λ 4481 of *Mg* II. In one or two cases a velocity has also been secured from *Hγ*, λλ 4045, 4063, and 4187 of *Fe* I. The velocities from the K line as given by Tremblot for 1938 were not included in the computations but are shown, on Figure 3, to be satisfied by the solution.

### ELEMENTS OF THE ORBIT OF THE G-TYPE STAR

A somewhat detailed description of this portion of the work appears to be useful, in view of the very special difficulties that arose in this case. In 1938 the data from published velocities by Frost and Lee[6] for 1903, 1904, 1905, 1906, and 1909, some single velocities from Lick Observatory in 1913 and 1915,[7] and a list of fourteen by Struve and Johnson in 1928–1929 were not sufficient for a determination of the period, though McLaughlin suggested a value of 15 years. Observations at Michigan were accordingly continued to 1941, when it was evident that no period of a number of years would satisfy these observations.

TABLE 1

| Phase | Julian Day 2400000+ | Velocity | Phase | Julian Day 2400000+ | Velocity |
|---|---|---|---|---|---|
| 0.600 | 32270 | −36 | 0.800 | 32347 | −37 |
| .650 | 32289 | 43 | 0.900 | 32386 | −31 |
| 0.700 | 32308 | −42 | | | |

A more careful examination of the individual velocities then showed that a steady progressive change within each season had been masked by the scatter and that each year's observations (which were grouped within a few months) fell a little earlier in the star's cycle than the set for the preceding year. The true period was evidently slightly more than a year or half a year. Several trials indicated a probable period from which it was expected that the velocity-curve would rise rapidly from minimum to maximum in the late autumn of 1941. The expected rise occurred during November, and observations were continued until the star was close to conjunction with the sun. Observations were resumed as early as possible in March, 1942, and these indicated that the period was close to 1 year instead of 6 months. A period of 386 days was finally derived, and continued observations fully confirmed this result when the velocities in July and August repeated those of June and July, 1941. The A-type stars also showed a center-of-mass-curve which reflected the velocity of the G-type star. It now appears that all doubt as to the period has been removed, even though there is a large unobserved region in the velocity-curves which cannot be filled in completely until 1947. (See Table 1 for predicted values corresponding to the dotted-line portions of Figure 2, which will be observed beginning about March 25, 1947.)

Individual observations were given a weight of either ½ or 1, and twenty-three normal places (see Table 2) were formed for a preliminary solution of the orbit. This was carried out by Russell's short method,[8] since this is most suitable for a curve having no observations precisely at the maximum.

[6] *Ap. J.*, **30**, 67, 1909.

[7] *Pub. Lick Obs.*, **16**, 269, 1928.

[8] *Ap. J.*, **40**, 282, 1914.

The period of 386 days was adopted as known, and the remaining five elements were then determined by a least-squares solution for the twenty-three normal places. The resulting elements are:

| Elements | Preliminary | Final |
|---|---|---|
| $P$ | 386.0 days | 386.0 days |
| $\gamma$ | $-23.4$ km/sec | $-23.3 \pm 0.22$ km/sec |
| $T$ | 218.7 days | $221 \pm 2.9$ days |
| $\omega$ | 272° | $277° \pm 5°$ |
| $e$ | 0.46 | $0.47 \pm 0.02$ |
| $K$ | 27 km/sec | $28 \pm 2$ km/sec |
| $a \sin i$ | 127,000,000 km | 131,000,000 km |

ORBIT OF THE CENTER OF MASS OF THE A-TYPE STARS

The velocities of the K line belonging only to the bright component of the system of period 1.85 days were used for the determination of the orbit of the center of mass of this system. (We shall refer to the velocity-curve of the latter as the "$\gamma_A$-curve.") From inspection of the plot of velocities in the 1.85-day orbit it was evident that there would be no justification for assuming orbits of these stars other than circular, and therefore

TABLE 2

NORMAL PLACES FOR THE G-TYPE STAR

| No. | Phase | Vel. | Wt. | O − C | No. | Phase | Vel. | Wt. | O − C |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 0.038 | −25.0 | 1.0 | −2.0 | 13 | 0.540 | −33.0 | 0.4 | +1.4 |
| 2 | .099 | 26.0 | 0.5 | +1.0 | 14 | .562 | −28.0 | .4 | −3.1 |
| 3 | .164 | 31.0 | 1.0 | +1.0 | 15 | .570 | −19.0 | .5 | +1.4 |
| 4 | .196 | 36.0 | 1.0 | −2.0 | 16 | .583 | −10.7 | .2 | +2.7 |
| 5 | .237 | 35.0 | 1.2 | +2.0 | 17 | .623 | 0.0 | .1 | −2.0 |
| 6 | .277 | 40.0 | 0.9 | 0.0 | 18 | .720 | + 3.0 | .2 | −1.0 |
| 7 | .311 | 42.0 | 0.7 | 0.0 | 19 | .792 | − 6.0 | .2 | −3.0 |
| 8 | .380 | 45.0 | 0.9 | +2.0 | 20 | .862 | − 5.0 | .2 | +4.0 |
| 9 | .404 | 50.0 | 0.9 | −2.0 | 21 | .909 | −12.0 | .4 | +1.0 |
| 10 | .443 | 50.0 | 1.0 | 0.0 | 22 | .948 | −14.0 | .5 | +2.0 |
| 11 | .499 | 46.3 | 0.9 | +0.6 | 23 | 0.988 | −17.0 | 0.5 | +2.0 |
| 12 | 0.530 | −42.0 | 0.4 | −2.8 | | | | | |

each individual observation was compared to the ordinate of a sine-curve to give residuals, each of which might be regarded as a measure of the velocity of the center of mass for the date considered. The mean residuals and mean phases in the 386-day period for groups of the velocities then gave normal places for the $\gamma_A$-curve. This method was used to find one value of $\gamma_A$ for 1938, one for 1939, one for 1940, three for 1941, and two for 1942.

The elements of this orbit, except for $K$, were taken from the orbit of the G-type giant, since the great number of observations obtained for the giant gave accurately those elements which must be the same for the two components of a system. The semi-amplitude of the orbit was estimated from the ratio of the ordinate (in km/sec) of the $\gamma_A$-curve to that of the G-type star at the same phase. An ephemeris from these elements, with $\omega$ equal to $\omega_G + 180° = 97°$, $P = 386$ days, $\gamma = -23.3$ km/sec, $e = 0.47$, and an approximate semiamplitude, yielded residuals predominantly negative and indicated an immediate revision to $K = 18$ km/sec. A least-squares solution was then carried out for $\delta K$, but the correction $\delta K$ was not considered significant; therefore the

value $K = 18$ km/sec was accepted, with the above elements for construction of the velocity-curve of the center of mass of the A-class stars. This curve was used in the solution of the orbits of the binaries, but upon its completion the $\gamma_A$-curve required a final adjustment, which gave $K = 19$ km/sec.

### SOLUTION OF THE ORBITS OF THE A-TYPE STARS FROM THE K LINE OF *Ca* II

The $\gamma_A$ velocity was eliminated from the observed velocities of the individual A-type stars, giving their velocities in the 1.85-day orbit. The date of each observation was corrected for the equation of light due to the orbital motion of the earth and also for that of the center of mass of the A-type pair.

A period of 1.85053 days was obtained before the solution of the center-of-mass orbit was made. When the above corrections had been applied to the velocities and to the Julian days, respectively, the longest base line available for refinement of the period was the span of four years, 1938 through 1942. The method of reciprocal periods was used, and a very small correction to the above period presented a more favorable coincidence of cycles; thus the solutions of the orbits were made with the assumed period

TABLE 3

NORMAL PLACES FOR THE VELOCITY OF THE CENTER OF MASS OF THE A-TYPE STAR SYSTEM

| Year | Wt. | Phase | Vel. | O − C* | Year | Wt. | Phase | Vel. | O − C* |
|---|---|---|---|---|---|---|---|---|---|
| 1942..... | 14 | 0.996 | −26 | 0 | 1938..... | 27 | 0.426 | − 7 | −1 |
| 1942..... | 11 | .144 | 17 | +2 | 1941..... | 6 | .483 | 7 | −1 |
| 1941..... | 16 | .182 | 18 | −1 | 1941..... | 5 | .536 | 20 | −6 |
| 1940..... | 8.5 | .252 | 13 | +1 | 1941..... | 9 | 0.568 | −24 | +1 |
| 1939..... | 23 | 0.290 | − 7 | +5 | | | | | |

* When $K = 19$ km/sec.

of 1.8505205 days. However, the use of the period carried to eight figures was merely a computational procedure required by the adopted value of the reciprocal. Only with future observations can the period be surely found to seven places. The probable error of the period is estimated as 0.000009 days from an examination of the possible shift of the velocity-curve of 1942 with respect to 1938 (not the maximum allowable shift). That the true period is the one given above, and not a value slightly more than 2 days, is shown by the satisfactory agreement of velocities from the plates taken at Mount Wilson and those measured by Tremblot in Paris, the difference in longitude between these observatories being 8 hours.

Final phases from $P = 1.8505205$ days and radial velocities (due to the motion of this binary alone) were plotted to form a composite curve for each star from which the normal places were formed (see Table 4). Weights were assigned to individual velocities on the basis of the quality and separation of the components of the K line, and the weights of the normal places depended solely on the sums of these single weights.

The value of $K$ for the bright component was first estimated closely by superimposing a sine-curve upon the composite velocity plot of that star. At the same time it was possible to read off $T'$, the time of superior conjunction of the brighter star.

For the ephemeris of a preliminary orbit we had the following elements: $P = 1.8505205$ days; $T' = 0.222$ day; $K = 90$ km/sec; we assume: $e = 0$, $\gamma = 0$. It was desirable next to carry out a least-squares solution for only three unknowns: $\delta K$, $\delta T'$, and $\delta\gamma$. Actually, there should be no correction to the center-of-mass velocity, since it has been accounted for in each season; but from the fitting of the sine-curve to the composite velocity plot and from the least-squares solution the correction was found

to be significant. From the order of magnitude of the probable errors the corrections to the assumed $T'$ and $K$ were inconsequential.

The elements of the orbit of the bright star then are:

| Elements | Preliminary | Corrected |
|---|---|---|
| $P$ | 1.8505205 days | 1.8505205 days |
| $\omega$ | 97° | 97° |
| $e$ | 0.0 | 0.0 |
| $\gamma$ | 0.0 | 0.0 |
| $K$ | 90.0 km/sec | 90±2 km/sec |
| $T'$ | 0.222 days | 0.219± .008 days |
| $a \sin i$ | ..... | 2,270,000 km |

For the faint component only the observations near maximum and minimum of the velocity-curve are entitled to any weight, since others are affected by blends with the stronger component and would give a much less accurate value of $K$. Four normal places were thus available at maximum, and four at minimum. When the same center-of-mass velocity as that of the bright component was adopted, the residuals showed an asymmetry. The best fit was obtained by trial and error, with $K = 100$ km/sec and with a center-of-mass velocity displaced by +2 km/sec relative to that of the bright star, making a total displacement of +3.8 km/sec relative to the adopted zero of the $\gamma_A$-curve.

TABLE 4

NORMAL PLACES FOR THE A-TYPE STARS

| Bright Component | | | | | Faint Component | | | | |
|---|---|---|---|---|---|---|---|---|---|
| No. | Phase | Vel. | Wt. | O − C | No. | Phase | Vel. | Wt. | O − C |
| 1 | 0.077 | +25.0 | 0.6 | + 0.2 | 1 | ..... | ..... | ..... | ..... |
| 2 | .115 | + 1.9 | 0.6 | − 1.7 | 2 | ..... | ..... | ..... | ..... |
| 3 | .156 | −11.0 | 0.6 | + 8.2 | 3 | ..... | ..... | ..... | ..... |
| 4 | .258 | −63.3 | 1.0 | + 3.3 | 4 | 0.261 | + 87.3 | 1.0 | + 7.4 |
| 5 | .344 | −86.8 | 1.0 | − 0.6 | 5 | .336 | + 98.0 | 1.0 | − 1.8 |
| 6 | .420 | −87.5 | 0.8 | − 4.8 | 6 | .417 | + 95.1 | 0.8 | − 2.0 |
| 7 | .455 | −78.1 | 0.8 | − 3.7 | 7 | .458 | + 98.3 | 0.7 | +12.0 |
| 8 | .564 | − 8.5 | 0.6 | +19.4 | 8 | ..... | ..... | ..... | ..... |
| 9 | .640 | + 1.4 | 0.6 | −12.4 | 9 | ..... | ..... | ..... | ..... |
| 10 | .696 | +35.7 | 0.8 | − 7.9 | 10 | ..... | ..... | ..... | ..... |
| 11 | .747 | +67.4 | 1.0 | + 1.2 | 11 | .746 | − 53.8 | 0.8 | +16.2 |
| 12 | .819 | +88.9 | 1.0 | + 2.2 | 12 | .818 | − 92.5 | 0.9 | + 0.2 |
| 13 | .877 | +88.7 | 1.0 | − 2.1 | 13 | .893 | −101.6 | 0.9 | − 1.0 |
| 14 | 0.964 | +76.5 | 1.0 | + 1.2 | 14 | 0.957 | − 70.3 | 0.9 | +12.8 |

Since the position of the center-of-mass axes for both A-type stars differed from zero, further revision of the $\gamma_A$-curve was necessary. Accordingly, residuals for each season were redetermined with the new elements for the bright star, and the value of $K$ was changed from 18 km/sec to 19 km/sec. This only slightly altered the maximum and minimum parts of the curve, and thus only twelve of the individual observations of the A-type stars were affected by +1 km/sec. They are listed with this adjusted velocity in the "Journal of Observations," Table 6. Since the latest residuals which were used for the redetermination of $K$ for the $\gamma_A$-curve were obtained with new elements and an assumed $\gamma = 0$, the correction to $\gamma = 0$ found in the orbit solutions of the two A-type components was then absorbed.

TABLE 5*

JOURNAL OF OBSERVATIONS FOR THE G-TYPE STAR
($P = 386.0$ Days)

| Year | Julian Day 2400000+ | Phase | Vel. in Km/Sec | Year | Julian Day 2400000+ | Phase | Vel. in Km/Sec |
|---|---|---|---|---|---|---|---|
| 1903..... | 16272.80 | 0.157 | −30 | 1938..... | 29138.62 | 0.488 | −44 |
| | 278.82 | .173 | −27 | | 140.61 | .494 | −45 |
| 1904..... | 16677.78 | .207 | −43 | | 143.57 | .501 | −50 |
| 1905..... | 17104.58 | .312 | −47 | | 144.61 | .504 | −49 |
| 1906..... | 17459.64 | .232 | −46 | | 146.59 | .509 | −42 |
| | 468.65 | .256 | −40 | 1939..... | 29419.80 | .217 | −28 |
| | 471.58 | .263 | −36 | | 420.72 | .219 | −30 |
| | 478.60 | .281 | −40 | | 420.81 | .220 | −30 |
| 1909..... | 18448.84 | .795 | +10 | | 423.71 | .227 | −32 |
| 1911..... | 19188.72 | .712 | −15† | | 423.88 | .228 | −32† |
| 1913..... | 19963.82 | .720 | − 3 | | 427.80 | .238 | −37 |
| | 65.70 | .724 | − 6 | | 429.81 | .243 | −42† |
| 1915..... | 20762.66 | .789 | −21 | | 431.70 | .248 | −35 |
| 1928..... | 25421.70 | .859 | − 5 | | 431.85 | .248 | −26 |
| | 435.75 | .896 | −15 | | 435.77 | .258 | −42 |
| | 439.70 | .906 | −14 | | 438.77 | .266 | −44 |
| | 444.76 | .919 | − 4 | | 439.82 | .269 | −41† |
| | 450.63 | .934 | −11 | | 440.72 | .271 | −36 |
| | 453.64 | .942 | −18 | | 441.67 | .274 | −45† |
| | 454.68 | .945 | −16 | | 445.65 | .284 | −37 |
| | 486.63 | .027 | −30 | | 445.73 | .284 | −34 |
| | 490.60 | .038 | −26 | | 447.80 | .290 | −45 |
| | 495.60 | .051 | −25 | | 448.67 | .292 | −32† |
| | 496.60 | .053 | −24 | | 448.80 | .292 | −38† |
| | 505.59 | .076 | −23 | | 451.69 | .300 | −44 |
| 1929..... | 25716.40 | .623 | + 7† | | 453.65 | .305 | −42 |
| | 857.76 | .989 | − 5† | | 454.80 | .308 | −50† |
| 1938..... | 29085.67 | .351 | −31† | | 456.63 | .312 | −41 |
| | 091.65 | .367 | −37 | | 456.72 | .313 | −39 |
| | 092.65 | .369 | −54 | | 480.63 | .374 | −49 |
| | 093.69 | .372 | −49 | | 481.71 | .377 | −40 |
| | 094.71 | .375 | −51 | | 485.67 | .388 | −43 |
| | 096.65 | .380 | −56† | | 486.66 | .390 | −49 |
| | 098.64 | .385 | −30 | | 487.58 | .392 | −53 |
| | 099.63 | .388 | −43 | | 490.63 | .400 | −57 |
| | 101.66 | .393 | −47† | | 492.66 | .406 | −55 |
| | 103.63 | .398 | −53 | 1940..... | 29785.80 | .165 | −29 |
| | 103.74 | .398 | −40 | | 806.76 | .204 | −30 |
| | 105.63 | .403 | −48 | | 810.69 | .230 | −32 |
| | 107.65 | .408 | −52 | | 812.69 | .235 | −37 |
| | 108.67 | .411 | −59† | | 817.65 | .248 | −32 |
| | 109.65 | .413 | −49 | | 820.67 | .256 | −42 |
| | 110.64 | .416 | −44 | | 823.80 | .264 | −47 |
| | 114.64 | .426 | −47 | | 831.63 | .284 | −38 |
| | 114.74 | .427 | −48 | | 842.68 | .312 | −38 |
| | 115.62 | .429 | −54 | | 845.70 | .320 | −42 |
| | 116.65 | .432 | −59† | 1941..... | 30164.74 | .147 | −28 |
| | 117.62 | .434 | −55 | | 170.67 | .162 | −30 |
| | 119.64 | .439 | −50 | | 171.68 | .165 | −36 |
| | 123.66 | .450 | −39† | | 171.76 | .165 | −34 |
| | 127.63 | .460 | −47 | | 172.68 | .167 | −39 |
| | 130.64 | .468 | −52 | | 172.75 | .168 | −31 |
| | 137.61 | 0.486 | −43 | | 177.63 | 0.180 | −27 |

* Note that the phases have no unit, being a fraction of the period.
† Half-weight.

TABLE 5—*Continued*

| Year | Julian Day 2400000+ | Phase | Vel. in Km/Sec | Year | Julian Day 2400000+ | Phase | Vel. in Km/Sec |
|---|---|---|---|---|---|---|---|
| 1941..... | 30177.70 | 0.180 | −28 | 1941..... | 30327.55 | 0.569 | −21† |
| | 179.63 | .185 | −34 | | 328.46 | .571 | −17 |
| | 180.66 | .188 | −32 | | 329.55 | .574 | −19 |
| | 180.72 | .188 | −40 | | 330.55 | .576 | −18 |
| | 181.63 | .191 | −33 | | 331.55 | .579 | −12 |
| | 181.79 | .191 | −34 | | 335.48 | .589 | − 8 |
| | 183.70 | .196 | −38 | 1942..... | 30442.93 | .868 | − 5 |
| | 184.62 | .198 | −40 | | 457.90 | .906 | −14† |
| | 184.68 | .198 | −35 | | 462.89 | .919 | −10† |
| | 185.62 | .201 | −43 | | 463.88 | .922 | −10† |
| | 187.66 | .206 | −31 | | 470.88 | .940 | −13† |
| | 273.55 | .429 | −54 | | 473.84 | .948 | −14 |
| | 275.54 | .434 | −48 | | 474.84 | .950 | −18 |
| | 284.53 | .457 | −53 | | 477.85 | .958 | −11 |
| | 289.54 | .470 | −47 | | 479.98 | .964 | −15 |
| | 301.48 | .501 | −51 | | 483.89 | .974 | −24† |
| | 301.50 | .501 | −51 | | 484.90 | .976 | −20† |
| | 302.47 | .504 | −43 | | 486.00 | .979 | −13 |
| | 302.48 | .504 | −45 | | 487.80 | .984 | −19 |
| | 311.46 | .527 | −42 | | 488.84 | .986 | −13 |
| | 311.47 | .527 | −45 | | 493.87 | .000 | −20 |
| | 312.48 | .530 | −44 | | 496.86 | .007 | −19 |
| | 313.47 | .532 | −41† | | 501.79 | .020 | −15 |
| | 313.48 | .532 | −34† | | 502.79 | .023 | −31 |
| | 315.46 | .537 | −32 | | 503.91 | .026 | −21 |
| | 315.48 | .537 | −38 | | 507.87 | .036 | −25 |
| | 316.47 | .540 | −31 | | 508.76 | .038 | −22 |
| | 316.49 | .540 | −32 | | 509.85 | .041 | −26 |
| | 318.46 | .545 | −35 | | 512.93 | .049 | −30† |
| | 318.48 | .545 | −36† | | 515.79 | .056 | −27 |
| | 323.46 | .558 | −30 | | 515.95 | .057 | −27 |
| | 323.48 | .558 | −31† | | 522.78 | .074 | −24 |
| | 325.46 | .563 | −28 | | 528.80 | .090 | −24 |
| | 325.48 | .563 | −25 | | 534.84 | .106 | −24 |
| | 325.55 | .563 | −21 | | 535.80 | .108 | −27 |
| | 326.47 | .566 | −22† | | 541.68 | .123 | −27† |
| | 326.56 | .566 | −27† | | 543.63 | .128 | −33 |
| | 327.46 | .568 | −17 | | 549.66 | .144 | −31 |
| | 327.49 | 0.568 | −20 | | 551.76 | 0.150 | −29 |

The effect of reflection on the velocity-curve of a close spectroscopic binary, as reported upon by Kopal, does not affect the velocity-curve of these A-type stars, since the largest correction to any velocity is 0.5 km/sec.

### THE VISUAL COMPANION TO THE TRIPLE SYSTEM

The spectrum of the faint visual companion (7.8 mag.) exhibited very strong hydrogen lines and a strong K line and is classified as A0. $H\epsilon$ appears unusually strong and broad. Some faint metallic lines in the spectrum were, in all probability, due to the bright component from which some light may have been spread over onto the slit during moments of poorer seeing. Since the position angle is approximately 318°, the difficulties of guiding upon the faint component alone increase with advancing hour angle when atmospheric refraction causes rapid apparent drift in declination.

TABLE 6

JOURNAL OF OBSERVATIONS FOR THE A-TYPE STARS

| YEAR | JULIAN DAY 2400000+ | BRIGHT STAR | | FINAL PHASE | FAINT STAR | | OTHER FINAL VELOCITIES | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | λ 4481 | | λ 4078 | |
| | | Obs. Vel. | Binary Vel.* | | Obs. Vel. | Binary Vel. | Strong | Weak | Strong | Weak |
| 1938..... | 29085.671 | − 19 | − 10 | 0.562 | − 19 | − 10 | − 3 | − 3 | ..... | ..... |
| | 091.653 | + 68 | + 76 | .794 | − 87 | − 79 | + 70 | −102 | ..... | ..... |
| | 092.652 | − 95 | − 87 | .334 | + 83 | + 91 | − 91 | +107 | ..... | ..... |
| | 093.691 | + 78 | + 86 | .896 | −118 | −110 | ..... | ..... | + 91 | † |
| | 094.712 | − 82 | − 74 | .448 | + 98 | +106 | ..... | ..... | − 52 | + 96 |
| | 098.647 | − 5 | + 3 | .574 | − 5 | + 3 | 00 | 00 | ..... | ..... |
| | 099.631 | − 4 | + 4 | .106 | − 4 | + 4 | ..... | ..... | ..... | ..... |
| | 103.635 | − 65 | − 58 | .270 | +108 | +115 | ..... | ..... | ..... | ..... |
| | 103.741 | − 88 | − 81 | .327 | + 96 | +103 | ..... | ..... | − 71 | +106 |
| | 105.631 | −100 | − 93 | .348 | + 92 | + 99 | ..... | ..... | − 91 | ..... |
| | 107.652 | −108 | −101 | .440 | ..... | ..... | ..... | ..... | −101 | + 83 |
| | 109.656 | − 33 | − 26 | .523 | + 57 | + 64 | ..... | ..... | − 62 | + 66 |
| | 110.644 | − 5 | + 2 | .057 | − 5 | + 2 | ..... | ..... | ..... | ..... |
| | 114.644 | − 62 | − 56 | .218 | +113 | +119 | ..... | ..... | ..... | ..... |
| | 114.745 | − 61 | − 55 | .273 | + 62 | + 68 | ..... | ..... | † | + 63 |
| | 115.626 | + 50 | + 56 | .750 | − 39 | − 33 | ..... | − 31 | ..... | ..... |
| | 116.654 | − 86 | − 80 | .305 | + 81 | + 87 | ..... | ..... | ..... | ..... |
| | 117.619 | + 72 | + 78 | .826 | −118 | −112 | ..... | ..... | ..... | ..... |
| | 119.643 | + 64 | + 70 | .920 | − 78 | − 72 | ..... | ..... | ..... | ..... |
| | 123.667 | + 8 | + 13 | .095 | + 8 | + 13 | ..... | ..... | ..... | ..... |
| | 127.636 | − 72 | − 67 | .240 | + 94 | + 99 | ..... | ..... | − 95 | + 81 |
| | 130.647 | + 86 | + 92 | .867 | − 96 | − 90 | + 85 | −100 | + 95 | † |
| | 137.617 | − 5 | + 1 | .633 | − 5 | + 1 | ..... | ..... | ..... | ..... |
| | 138.625 | − 34 | − 28 | .178 | ..... | ..... | ..... | ..... | ..... | ..... |
| | 143.571 | + 75 | + 83 | .851 | −115 | −107 | ..... | ..... | + 90 | † |
| | 144.613 | − 98 | − 90 | .414 | + 87 | + 95 | ..... | ..... | ..... | ..... |
| | 146.593 | − 72 | − 63 | .484 | + 66 | + 75 | ..... | ..... | ..... | ..... |
| 1939..... | 29419.803 | − 7 | + 8 | .123 | − 7 | + 8 | ..... | ..... | ..... | ..... |
| | 420.723 | − 10 | + 5 | .620 | − 10 | + 5 | ..... | ..... | ..... | ..... |
| | 420.815 | − 8 | + 7 | .670 | − 8 | + 7 | ..... | ..... | ..... | ..... |
| | 423.710 | − 63 | − 48 | .235 | + 62 | + 77 | ..... | ..... | − 72 | +108 |
| | 423.880 | − 78 | − 63 | .326 | + 86 | +101 | ..... | ..... | ..... | ..... |
| | 427.797 | − 75 | − 61 | .443 | +109 | +123 | ..... | ..... | ..... | ..... |
| | 431.700 | − 13 | + 1 | .552 | − 13 | + 1 | ..... | ..... | ..... | ..... |
| | 431.852 | + 12 | + 26 | .634 | + 12 | + 26 | ..... | ..... | ..... | ..... |
| | 435.770 | + 73 | + 86 | .751 | − 58 | − 45 | ..... | ..... | † | − 25 |
| | 438.776 | −104 | − 91 | .375 | + 89 | +102 | ..... | ..... | † | + 83 |
| | 439.822 | + 93 | +106 | .941 | −122 | −109 | † | − 95 | + 96 | − 73 |
| | 440.725 | −108 | − 95 | .429 | +102 | +115 | ..... | ..... | − 64 | + 93 |
| | 441.669 | + 42 | + 55 | .939 | −101 | − 88 | + 74 | − 81 | † | −100 |
| | 445.650 | − 16 | − 4 | .090 | − 16 | − 4 | ..... | ..... | ..... | ..... |
| | 445.737 | − 10 | + 2 | .137 | − 10 | + 2 | ..... | ..... | ..... | ..... |
| | 447.806 | − 62 | − 50 | .256 | +120 | +132 | † | + 86 | − 46 | + 76 |
| | 448.675 | ..... | ..... | .725 | − 34 | − 22 | ..... | ..... | ..... | ..... |
| | 451.691 | −104 | − 93 | .355 | +103 | +114 | − 76 | ..... | ..... | ..... |
| | 453.656 | − 72 | − 61 | .417 | + 76 | + 87 | ..... | ..... | † | + 92 |
| | 456.726 | + 6 | + 17 | .076 | ..... | ..... | ..... | ..... | ..... | ..... |
| | 480.636 | + 62 | + 70 | .996 | − 39 | − 31 | + 60 | − 80 | ..... | ..... |
| | 481.715 | − 22 | − 14 | 0.579 | − 22 | − 14 | − 20 | ..... | ..... | ..... |

* Velocity of the A-type star indicating motion in the line of sight due only to its motion about the other component.

† Velocity was measured but was too small numerically, because of blending with the G spectrum.

TABLE 6—*Continued*

| Year | Julian Day 2400000+ | Bright Star | | Final Phase | Faint Star | | Other Final Velocities | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Obs. Vel. | Binary Vel.* | | Obs. Vel. | Binary Vel. | λ 4481 | | λ 4078 | |
| | | | | | | | Strong | Weak | Strong | Weak |
| 1939 | 29485.675 | + 45 | + 53 | 0.719 | − 64 | − 56 | + 46 | ..... | ..... | − 58 |
| | 486.661 | − 46 | − 38 | .252 | + 59 | + 67 | ..... | ..... | ..... | ..... |
| | 487.587 | + 68 | + 76 | .752 | − 66 | − 58 | ..... | ..... | ..... | ..... |
| | 490.631 | −105 | − 98 | .398 | ..... | ..... | − 90 | + 94 | − 98 | + 80 |
| 1940 | 29785.800 | + 72 | + 90 | .904 | −129 | −111 | ..... | ..... | ..... | ..... |
| | 810.691 | −102 | − 87 | .354 | + 94 | +109 | ..... | ..... | ..... | ..... |
| | 812.696 | − 86 | − 72 | .438 | + 86 | +100 | ..... | ..... | ..... | ..... |
| | 817.656 | − 6 | + 8 | .118 | − 6 | + 8 | ..... | ..... | ..... | ..... |
| | 820.669 | + 42 | + 56 | .746 | − 85 | − 71 | † | − 78 | ..... | ..... |
| | 823.804 | − 94 | − 81 | .440 | +116 | +129 | − 69 | † | ..... | ..... |
| | 824.591 | + 79 | + 92 | .866 | −112 | − 99 | ..... | ..... | ..... | ..... |
| | 842.682 | − 20 | − 9 | .642 | − 20 | − 9 | ..... | ..... | ..... | ..... |
| | 845.699 | − 82 | − 72 | .272 | + 82 | + 92 | ..... | ..... | ..... | ..... |
| 1941 | 30164.744 | + 24 | + 43 | .680 | − 50 | − 31 | + 41 | † | ..... | ..... |
| | 171.678 | −103 | − 85 | .427 | ..... | ..... | − 87 | + 91 | ..... | ..... |
| | 171.763 | − 98 | − 80 | .473 | + 65 | + 83 | − 66 | + 71 | ..... | ..... |
| | 172.686 | + 60 | + 78 | .971 | − 83 | − 65 | + 62 | − 80 | ..... | ..... |
| | 172.752 | + 49 | + 67 | .007 | − 95 | − 77 | + 57 | − 77 | † | − 79 |
| | 177.635 | − 6 | + 11 | .646 | − 6 | + 11 | ..... | ..... | ..... | ..... |
| | 177.702 | − 14 | + 3 | .682 | − 14 | + 3 | ..... | ..... | ..... | ..... |
| | 179.630 | + 28 | + 45 | .724 | − 71 | − 54 | + 44 | − 78 | ..... | ..... |
| | 180.665 | − 93 | − 76 | .284 | + 64 | + 81 | − 77 | + 79 | ..... | ..... |
| | 180.721 | − 98 | − 81 | .314 | + 79 | + 96 | −106 | +121 | − 98 | † |
| | 181.633 | + 70 | + 87 | .807 | −104 | − 87 | ..... | ..... | † | − 84 |
| | 181.790 | + 65 | + 72 | .891 | ..... | ..... | † | −101 | † | −111 |
| | 183.700 | + 88 | +104 | .924 | − 74 | − 58 | + 77 | −104 | † | −100 |
| | 184.623 | −115 | − 99 | .422 | + 80 | + 96 | ..... | ..... | ..... | ..... |
| | 184.691 | − 84 | − 68 | .459 | + 93 | +109 | − 56 | ..... | ..... | ..... |
| | 187.662 | + 18 | + 34 | .065 | ..... | ..... | + 43 | ..... | ..... | ..... |
| | 273.552 | −116 | −110 | .479 | + 95 | +101 | ..... | ..... | ..... | ..... |
| | 301.477 | − 20 | − 12 | .570 | − 20 | − 12 | ..... | ..... | ..... | ..... |
| | 301.499 | − 30 | − 22 | .582 | − 30 | − 22 | ..... | ..... | ..... | ..... |
| | 302.470 | 00 | + 8 | .106 | 00 | + 8 | ..... | ..... | ..... | ..... |
| | 302.482 | − 14 | − 6 | .113 | − 14 | − 6 | ..... | ..... | ..... | ..... |
| | 311.459 | + 83 | + 96 | .964 | − 58 | − 45 | ..... | ..... | ..... | ..... |
| | 315.458 | − 30 | − 15 | .125 | − 30 | − 15 | ..... | ..... | ..... | ..... |
| | 315.481 | − 28 | − 13 | .137 | − 28 | − 13 | ..... | ..... | ..... | ..... |
| | 316.464 | − 17 | − 1 | .668 | − 17 | − 1 | ..... | ..... | ..... | ..... |
| | 316.487 | + 10 | + 26 | .681 | + 10 | + 26 | ..... | ..... | ..... | ..... |
| | 323.457 | −103 | − 84 | .447 | + 75 | + 94 | ..... | ..... | ..... | ..... |
| | 323.478 | − 99 | − 80 | .459 | + 65 | + 84 | ..... | ..... | ..... | ..... |
| | 325.551 | − 20 | + 3 | .578 | − 20 | + 3 | − 1 | − 1 | ..... | ..... |
| | 327.460 | − 21 | + 4 | .610 | − 21 | + 4 | ..... | ..... | ..... | ..... |
| | 327.551 | − 24 | + 1 | .659 | − 24 | + 1 | ..... | ..... | ..... | ..... |
| | 328.457 | − 66 | − 40 | .149 | ..... | ..... | ..... | ..... | ..... | ..... |
| | 329.551 | + 42 | + 69 | .740 | − 91 | − 64 | + 87 | − 93 | ..... | ..... |
| | 330.551 | −109 | − 82 | .280 | + 77 | +104 | − 71 | + 86 | − 79 | ..... |
| | 331.549 | + 75 | +103 | .820 | −141 | −113 | + 87 | ..... | ..... | − 66 |
| 1942 | 30473.841 | + 18 | + 47 | .713 | −108 | − 79 | ..... | ..... | ..... | ..... |
| | 474.635 | −111 | − 82 | .250 | + 68 | + 97 | − 64 | ..... | ..... | ..... |
| | 477.850 | + 49 | + 77 | 0.880 | −148 | −120 | + 68 | − 79 | ..... | ..... |

TABLE 6—*Continued*

| Year | Julian Day 2400000+ | Bright Star | | Final Phase | Faint Star | | Other Final Velocities | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Obs. Vel. | Binary Vel.* | | Obs. Vel. | Binary Vel. | λ 4481 | | λ 4078 | |
| | | | | | | | Strong | Weak | Strong | Weak |
| 1942..... | 30479.984 | + 68 | + 96 | 0.033 | −100 | − 72 | ..... | ..... | † | − 74 |
| | 483.889 | − 27 | 00 | .143 | − 27 | 00 | ..... | ..... | ..... | ..... |
| | 484.897 | + 5 | + 32 | .688 | −105 | − 78 | ..... | ..... | ..... | ..... |
| | 485.996 | −117 | − 90 | .282 | + 24 | + 51 | − 70 | + 66 | ..... | ..... |
| | 487.797 | − 93 | − 66 | .255 | + 45 | + 72 | − 59 | + 69 | ..... | ..... |
| | 488.843 | + 57 | + 84 | .820 | −116 | − 89 | ..... | ..... | ..... | ..... |
| | 493.873 | − 22 | + 4 | .539 | − 22 | + 4 | ..... | ..... | ..... | ..... |
| | 496.860 | − 20 | + 6 | .153 | − 20 | + 6 | ..... | ..... | ..... | ..... |
| | 501.788 | + 59 | + 84 | .816 | −112 | − 87 | ..... | ..... | ..... | ..... |
| | 502.793 | −115 | − 90 | .359 | + 62 | + 87 | + 88 | − 90 | ..... | ..... |
| | 503.907 | + 54 | + 79 | .961 | −119 | − 94 | ..... | ..... | ..... | ..... |
| | 506.949 | − 30 | − 6 | .604 | ..... | ..... | ..... | ..... | ..... | ..... |
| | 507.867 | − 7 | + 17 | .100 | − 7 | + 17 | ..... | ..... | ..... | ..... |
| | 512.930 | + 68 | + 92 | .837 | −111 | − 87 | ..... | ..... | ..... | ..... |
| | 515.946 | −108 | − 85 | .466 | + 68 | + 91 | ..... | ..... | ..... | ..... |
| | 522.785 | − 54 | − 32 | .162 | ..... | ..... | − 76 | † | ..... | ..... |
| | 528.801 | −103 | − 81 | .413 | + 74 | + 96 | ..... | ..... | ..... | ..... |
| | 534.846 | + 11 | + 32 | .679 | ..... | ..... | ..... | ..... | ..... | ..... |
| | 535.805 | − 27 | − 6 | .197 | − 27 | − 6 | ..... | ..... | − 89 | ..... |
| | 543.635 | −109 | − 89 | .429 | ..... | ..... | + 74 | −111 | ..... | ..... |
| | 551.758 | + 84 | +103 | .818 | −104 | − 85 | ..... | ..... | ..... | ..... |
| | 576.631 | − 82 | − 66 | .259 | + 73 | + 89 | ..... | ..... | ..... | ..... |
| | 576.734 | − 99 | − 83 | .315 | + 93 | +109 | ..... | ..... | ..... | ..... |
| | 577.734 | + 85 | +100 | .855 | ..... | ..... | ..... | ..... | ..... | ..... |
| | 577.772 | + 74 | + 89 | 0.876 | − 87 | − 72 | ..... | ..... | ..... | ..... |

TABLE 7

| | *G* | *A* (Primary Plus Secondary) | *A* | |
|---|---|---|---|---|
| | | | Primary | Secondary |
| $K$..... | 28 | 19 km/sec | 90 km/sec | 100 km/sec |
| $m^3 \sin^3 i/(m_1+m_2)^2$..... | 0.189 | 0.606 | 0.192 | 0.140 |
| $m \sin^3 i$..... | 1.16 | 1.70 | 0.694 | 0.624 |
| $m_2/m_1$..... | 1.47 | | 0.90 | |

The spectrum was photographed twice on July 16 with a camera lens 3.25 inches in focal length and twice on August 25, 1942, with a camera lens 6 inches in focal length attached to the two-prism spectrograph of the 37-inch reflector. The dispersions of these plates were approximately 145 A/mm and 80 A/mm, respectively. In all the spectra the $H\epsilon$ line was very strong and wide, and therefore was omitted from the measures. Below are recorded the velocities found on the four plates from the three lines: *Ca* II K, $H\delta$, and $H\gamma$. Those obtained with the shorter camera must be given low weight. No deductions can definitely be made from these velocities, but it will be interesting to ascertain from

spectrograms obtained in the future whether or not this star is a binary. There is a large probability that this is so from consideration of the order of size of these negative velocities, even allowing a large error. It should be remembered that the velocity of the center of mass of the triple system of the bright component is −23.3 km/sec.

| Date | Julian Day | Camera | Velocity | Total Weight |
|---|---|---|---|---|
| July 16..... | 2430557.706 | 3-inch | −54 km/sec | 2.5 |
| 16..... | 557.729 | 3-inch | 44 | 2.5 |
| Aug. 25..... | 597.611 | 6-inch | 32* | 2.0 |
| 25..... | 597.671 | 6-inch | −44 | 2.5 |

*This velocity is affected by the measures of overexposed comparison lines showing a coma effect.

## INTERSTELLAR CALCIUM

On several plates where the components of the K line were widely separated, there seemed to be an extremely faint line between them. On the possibility of this being an interstellar line, and not just grain effect, measures were made of the line on six plates which showed it most distinctly. The six velocities measured are listed here:

| Julian Day | Velocity | Julian Day | Velocity |
|---|---|---|---|
| 2429116.654..... | −10 km/sec | 2430180.721..... | −19 km/sec |
| 130.647..... | 17 | 184.623..... | 15 |
| 146.593..... | − 7 | 503.907..... | −25 |

The mean of the above velocities is −16 km/sec. The line-of-sight component of the solar motion in the direction of d Serpentis is −17.5 km/sec.

## DISCUSSION

The mass functions and the values of $m \sin^3 i$ for each star of the triple system are given in Table 7, with the mass ratio for each binary. If the G-type star is to be a giant, as indicated by the strength of its spectrum compared with that of the two A-type stars, its mass must be much more than $1.16\odot$, and therefore $i$ cannot be close to 90°. Since the values of $m \sin^3 i$ for the two A-type stars are small, compared with their total $m \sin^3 i$ as determined from their 386-day orbit, and since the latter orbit has an inclination far from 90°, it is evident that no eclipse can occur in the A-type binary system.

With the foregoing knowledge, the appearance of the spectra, and the dynamical parallax of the system,[9] we can estimate the masses themselves. From a comparison of the spectra of d Serpentis and α Aurigae (Sp. G0, $M_v = M_b = +0.1$) and an examination of the "filling-up" of the G-type absorption lines in d Serpentis, it was estimated that the continuous spectra due to the G-type star and to the A-type pair were of about equal intensity at $\lambda = 4200$. The difference in absolute magnitude ($\Delta M$) between the giant and one of the A-type stars was found from the use of Planck's formula for the region λ 4200A with $T_G = 5200°$ K and $T_{A2} = 9700°$ K. Then $E_G = 3.98 \times 10^{14}$ ergs/cm²sec and $E_A = 8.63 \times 10^{15}$ ergs/cm²sec. For simplicity, it may be assumed that we have two A-type stars of equal luminosity and mass. Hence, $L_G = 2L_A$ at $\lambda = 4200$, and it follows that $R_G/R_A = \sqrt{2E_A/E_G} = 6.58$. For visual light of effective wave length 5290 A, $E'_G = 4.88 \times 10^{14}$ ergs/cm²sec and $E'_A = 5.82 \times 10^{15}$ ergs/cm²sec. These

[9] Russell and Moore, *The Masses of the Stars*, University of Chicago Press, 1940.

quantities and the ratio of the radii give $L'_G/L'_A = 3.64$. Thus the difference between the visual absolute magnitudes of the G-type and one A-type star is $\Delta M = 1.40$. When the corrections for stars of types G and $A_2$ have been applied,[10] the difference in bolometric absolute magnitude for use with the mass-luminosity relation is $\Delta M_0 = 1.13$. The empirical formula for the slope of the mass-luminosity-curve[11] is $\Delta \log \overline{\text{mass}}^{1/3} = 0.04$ ($\Delta M_b$) and yields for the two A-type stars, relative to the G-type star, a mass ratio of 1.46. The observed value given in Table 7 is 1.47.

It is interesting to note that, if we assume $M_v = 0$ for the star with gG0 spectrum and use the bolometric corrections and formula for the mass-luminosity relation mentioned above, the masses of the stars are approximately 3.7⊙, 2.9⊙, and 2.7⊙ for the G-type, A-type primary, and secondary, respectively. The inclinations which follow are approximately 43° for the orbit of the G-type star and center of mass of the binary system, and approximately 38° for that of the binary system itself. The values of the semimajor axes then would be 193,000,000 km for the G-type star and 3,700,000 km and 4,100,000 km for the primary and secondary A-type stars. The apparent visual magnitudes corresponding to the above masses and absolute magnitudes are 5.8, 7.0, and 7.5, respectively. These individual magnitudes yield a composite apparent visual magnitude of 5.3, which agrees satisfactorily with the photometrically determined value 5.33 mag. given in the *Henry Draper Catalogue*. From Russell's approximate formula, $M_v = (29{,}500/T) - 5 \log R - 0.08$, using $T_G = 5200°$ K and $T_A = 9700°$ K, the radii of the individual stars of d Serpentis are about 13⊙, 2.2⊙, and 1.8⊙, or 9,000,000 km, 1,500,000 km, and 1,300,000 km.

I wish to express my most sincere thanks and appreciation to Dr. Dean B. McLaughlin for his patient assistance and helpful suggestions throughout this investigation. To Dr. Walter S. Adams, of the Mount Wilson Observatory, I am deeply indebted for his kindness in having spectrograms of this star taken at the times when they were most needed; and to Dr. Otto Struve, of the Yerkes Observatory, for his kindness in sending spectrograms taken in 1928–1929. My grateful appreciation is extended also to the Ann Arbor–Ypsilanti Branch of the American Association of University Women for the May Preston Slosson Fellowship in 1941–1942.

[10] *Ap. J.*, **88**, 446, 1938.

[11] Russell and Moore, *op. cit.*

# THE SPECTRUM OF $\alpha^2$ CANUM VENATICORUM*

O. STRUVE AND P. SWINGS
Yerkes and McDonald Observatories
*Received July 25, 1943*

ABSTRACT

A new list of wave lengths containing 3107 absorption lines between λ 3087.9 and λ 4740.6 has been obtained from 28 spectrograms taken at the Mount Wilson and the McDonald observatories. Of these plates, 18 were obtained with a dispersion of around 3 A/mm, while the other plates, used in the ultraviolet region, had 20 A/mm. The identifications are based upon all available laboratory material and show that all singly ionized rare earths which have been measured in the laboratory and which have a sufficient number of lines in the region covered by the stellar spectrograms are present. One doubly ionized rare earth, *Ce* III, is almost certainly present, and others may contribute to blends. The intensities of all rare-earth lines are variable in a period of 5.5 days and follow the pattern of the *Eu* II lines (designated as group A). The lines of *Cr* II and some other elements vary in the opposite sense (group B), while certain other lines—*Si* II, *Mg* II, etc.—do not appreciably change in intensity (group C).

The radial velocities as measured from the lines of different elements also fall into three groups, designated as a, b, and c, which roughly correspond to the intensity groups A, B, and C. Group a, consisting of the rare earths and some other elements predominantly of low ionization potential, shows a shallow minimum of velocity at phase 4.5 days after maximum *Eu* II intensity and a sharp maximum of velocity at phase 1.5 days. Group b, represented by *Cr II* and some other elements, shows a velocity-curve with a double wave. The highest maximum is at phase 5.0 days and the deepest minimum at phase 0.7 day. Group c, consisting of *Mg* II, *Si* II, *H*, and *Ca* II, shows no appreciable variation.

A recent review[1] of the problem presented by the variable line-intensities in $\alpha^2$ Canum Venaticorum has shown that several important conclusions rested upon somewhat inadequate observational data. In particular, there exists as yet no satisfactory list of the absorption lines in this remarkable spectrum. The most complete previous set of measurements was obtained by W. W. Morgan[2] on Yerkes single-prism spectrograms and covers the region λλ 3913–4572, with a linear dispersion of 30 A/mm at λ 4500. The more recent work by Tai[3] contains fewer lines and therefore adds relatively little to Morgan's identifications. The spectrum is exceedingly rich in lines. With small, or even with moderately large, dispersion the great majority of the lines are blends—many of which have never before been identified or even measured. Since Baxandall's discovery in 1910[4] that five strong absorption lines, measured by Belopolsky and found by the latter to have variable intensities, were due to the rare earth europium, several other ionized rare-earth atoms have been identified in $\alpha^2$ CVn, though until recently[1] there existed little agreement among different observers.

The purpose of this investigation is to present as complete a list of wave lengths and identifications as can be obtained at the present time and to study the variations in radial velocities presented by lines of different atoms. There has been some controversy concerning the reality of the changes in radial velocity first observed by Belopolsky for *Eu* II; and for a number of years the opinion appeared justified that, in some of these lines at least, the observed variations were caused by disturbing blends near minimum intensity of *Eu* II. The reality of the changes in velocity was definitely established by our preliminary measurements of McDonald Observatory coudé spectrograms.[1]

* *Contributions from the McDonald Observatory, University of Texas*, No. 78.

[1] Struve, *Proc. Amer. Phil. Soc.*, **85**, 349, 1942; Struve and Swings, *Observatory*, **64**, 291, 1942. Since these reviews were written, Nikonov and Brodskaja (*Bull. Acad. Sci. Georgian S.S.R.*, **3**, No. 7, 657, 1942) have found that the star changes in color-temperature by about 2000°, being bluest when the total light is at minimum.

[2] *Pub. Yerkes Obs.*, **7**, Part III, 1935.

[3] *M.N.*, **100**, 94, 1939.

[4] *Observatory*, **36**, 440, 1913.

The tables presented in this paper are based upon a number of spectrograms obtained at the Mount Wilson and McDonald observatories. The nine McDonald coudé plates have already been used in part.[1] They extend from about λ 3900 to λ 4800. The dispersing system consists of two large prisms of Chance glass, figured by Hilger and giving excellent definition over the entire range. The emulsion used was Eastman Ia0. The dispersion varies from 1.9 A/mm at λ 3933 to 4.5 A/mm at λ 5000.

We are greatly indebted to Dr. W. S. Adams, director of the Mount Wilson Observatory, for extending to us the use of his exquisite coudé spectrograms, also nine in number, which were taken with various adjustments of a large plane grating ruled on aluminum on glass. These spectrograms extend over a very large range in wave lengths and are uniformly of excellent quality. The dispersion is 3 A/mm. We have reproduced in Plates XXIII–XXX a number of the best spectrograms of each observatory. The changes in the line-intensities with phase are very conspicuous. The McDonald plates were taken through the glass (a practice which was necessitated by the large amount of curvature of our plateholders and which has since been abandoned because of a new technique which permits us to bend the plates sufficiently without breaking them), and this accounts for some of the irregular spots on the reproductions. The extreme ultraviolet region, from λ 3087.9 to λ 3408.0, has been measured on McDonald Observatory Cassegrain quartz spectrograms, having a dispersion of 20 A/mm at λ 3250 or 40 A/mm at λ 3933. These plates were obtained on Eastman Process emulsion and are of fine quality, but the dispersion was insufficient to resolve many of the blends. The Cassegrain quartz plates (*CQ*) were measured by Swings. All high-dispersion plates were measured by Struve. The identifications were made by Swings and were later in part reexamined by Struve. Because of the unusually large amount of work involved in these measurements, Struve measured all eighteen coudé plates in one direction and later remeasured two of them, Cd 81 and MtW 1992, in the reverse direction. The reductions were made quite independently, and the comparisons of direct and reverse measures furnish a valuable indication of the precision and of the essential absence of systematic differences in the two sets. Although a small tendency exists in each plate for strong and weak lines to differ slightly in the direct and the reverse measurements, the trend of the two spectrograms is opposite in sense. Hence it may be concluded that for the relatively broad lines of $\alpha^2$ CVn no systematic errors in excess of 0.01 A have been introduced into the results. The actual precision of the faintest lines should be of the order of 0.02 A, and of the stronger lines it should be more nearly of the order of 0.01 A.

The phases used in this paper were computed with the formula established by Miss G. Farnsworth:[5]

$$\text{Maximum intensity of } Eu\text{ II} = \text{JD } 2419869.720 + 5.46939E.$$

This formula satisfactorily predicts the phase of the maximum *Eu* II intensity, but it is possible that there are small departures from one cycle to another in the curve of intensity plotted against time. Hence the combination of observations made in different years may not be rigorously correct; unfortunately, the high-dispersion material is not sufficient to study possible departures from the mean curves.

Table 1 covers the region λλ 3088–3315 and is based upon only one spectrogram at phase $3^d77$, where the rare-earth lines should be weak. The contributions of these lines to blends, which should become important at other phases, are indicated in a separate column.

Table 2 gives the region λλ 3317–3408 and is based upon three spectrograms at phases $0^d47$, $1^d46$, and $4^d93$, which were measured from λ 3317 to λ 3369, and upon six spectrograms, which were measured from λ 3369 to λ 3408.

[5] *Ap. J.*, **75**, 364, 1932.

Table 3 is based upon nine Mount Wilson coudé plates and one McDonald coudé plate. The manner in which the phases of some of the plates were combined for the forming of average wave lengths and intensities is shown in Table 7.

All wave lengths have been corrected to the sun in the usual manner. The curvature correction was applied to the McDonald plates but was, of course, neglected for the Mount Wilson plates, which were taken with a grating.

The intensities of the star lines are rough estimates and are not intended for a study of the variations of the intensities, because they are affected by underexposure or overexposure of the region in question. The illustrations give a far better idea of the variations. Intensities greater than 9 are shown by the symbol $x$ in the tables. An intensity of 0 does not mean that the line is absent, but a single measure of such a line is rather doubtful and may not be real.

The work of identification was especially difficult for the following reasons:

*a*) The variation of $\lambda$ with phase. This variation may be so different for two atoms, A and B, that a line may be single at one phase and become double at another phase.

*b*) The unsatisfactory state of laboratory data for certain rare earths.

*c*) Considerable differences which may exist between the laboratory and the stellar intensities. Let us adopt $T_{exc} = 10{,}000°$ for $\alpha^2$ CVn and $T_{exc} = 5{,}000°$ for an arc. Table 8 gives the ratio $(I_1/I_2)_{arc}/(I_1/I_2)_{\alpha^2 CVn}$ for various differences in excitation potential of the two lines. Hence high-level lines may be considerably enhanced in $\alpha^2$ CVn relative to their laboratory intensities. The criterion of "arc intensity" (as applied by Tai, for example) is not reliable, although it may still be the best one could use in many cases when a term classification is not available. Whenever a term classification is known, the identifications have been discussed on the basis of multiplet intensity relations.

*d*) A contribution of minor importance at a specific phase may become important at some other phase (at least as far as $v_{rad}$ is concerned). Hence many minor contributions have been included in the tables.

The list of identifications gives the probable major contributors first. These are followed by minor, but appreciable, contributors. Less important contributors and uncertain contributors are given in parentheses.

The laboratory material used for identifications consisted of the following:

*a*) Miss Moore's original multiplet table, combined with new M.I.T. wave lengths wherever advisable.

*b*) New material on *Ne* II, *A* II, *P* II, *Fe* I, etc.

*c*) Considerable unpublished material generously supplied by Mrs. Sitterly (parts of her revised multiplet table) and by Dr. A. S. King for: *Fe* II, *Cr* II, *Ti* II, *Mn* II, *Co* II, *Ni* II, *Sc* II, *Cu* II, *Ce* II, *Pr* II, *Nd* II, *Sm* II, *Eu* II, *Gd* II, *Dy* II, *Tm* II, *Yb* II, *Lu* II.

*d*) Meggers' and Moore's analysis of *V* II.[6]

*e*) No term analysis is available for *Tb* II, *Dy* II, *Ho* II, *Er* II. For *Dy* II, a temperature classification by A. S. King is available over the whole astronomical region, but it seems to concern only the strong lines. A summarized copy belonging to Mrs. Sitterly was used.

For *Ho* II and *Tb* II, King's temperature classification covers only the region $\lambda\lambda$ 3836–4680. Hence the M.I.T. table had to be used for $\lambda < 3836$. Only the *Ho* and *Tb* lines have been entered, which are observed in the spark (the separation of *Ho* I–II and *Tb* I–II is not known for $\lambda < 3836$). The corresponding identifications are marked *Ho* (II?) and *Tb* (II?), and the intensities denoted by *S* are taken from the spark column of the M.I.T. table.

A recent temperature classification of *Gd* II extending over the whole astronomical region was received from Dr. A. S. King prior to publication; it was used with considerable success.

For erbium, only the old work of Exner and Hascheck and of Eder is available. This does not separate *Er* I and *Er* II. Over the whole astronomical region the wave lengths

[6] *Jour. Res., Nat. Bur. Stand.*, **25**, 83, 1940.

were taken from the M.I.T. table, for the lines only which appear in the spark. These wave lengths may be less satisfactory than for most other elements.

Generally speaking, the term analyses are still very incomplete for the rare earths. Hence the temperature classifications were used extensively.

*f*) Nothing has been published on the doubly ionized rare earths, except *Ce* III.[7] Yet it is very probable that a number of unidentified lines are due to *Eu* III, *Gd* III, *Dy* III, etc.

*g*) Each wave length of $\alpha^2$ CVn was compared with the neighboring wave lengths in the M.I.T. table.

With regard to the elements represented in $\alpha^2$ CVn the following notes are pertinent:

*a*) *Ne* II and *A* II. Probably pure chance coincidences or minor contributions.

*b*) *Sc* II. Extremely weak compared with $\alpha$ Cygni.

*c*) Singly ionized rare earths. The evidence is probably satisfactory for all singly ionized rare earths, except *Yb* II and *Er* II. *Yb* II is very faint, yet almost certainly present. The uncertainty of *Er* II is due to the lack of reliable laboratory data.

*d*) Doubly ionized rare earths. These identifications were made with the help of unpublished data kindly supplied by Dr. A. S. King.

*Ce III*.—The stellar evidence is summarized in Table 9. The following multiplets are present: $fs\,^3F^0-fp\,^3F$, $fs\,^3F^0-fp\,^3G$, $fs\,^3F^0-fp\,^1F^3$, $fs\,^3F^0-d^2\,^1G_4$, $fs\,^1F^0{}_3-fp\,^3F$, $fs\,^1F^0{}_3-fp\,^1F$, $fs\,^1F^0{}_3-d^2\,^1G_4$.

*Eu III* ($\lambda\lambda$ 2900–3194).—The region covered by King's list was taken only on *CQ* spectrograms and cannot provide reliable identifications. The *Eu* III line $\lambda$ 3183.7(100) may contribute, but it is badly blended by *Cr* II.

*Gd III* ($\lambda\lambda$ 2900–3177).—$\lambda$ 3118.0 (1000) may contribute. This region was taken only on *CQ* spectrograms.

*Sm III* ($\lambda\lambda$ 2903–3398.4).—No definite evidence; *Sm* III contributes probably in a number of blends, but the region is too crowded.

*Nd III* ($\lambda\lambda$ 2899–3431).—Contributions by *Nd* III probably improve the identifications of blends.

*Pr III* ($\lambda\lambda$ 3147–3568).—Most lines are blended; but their contributions improve the identification of the blends; $\lambda$ 3397.5(600) cannot be appreciably blended and is probably present.

*La III*.—$\lambda$ 3517.14 may be present.

Table 4 contains the best lines for a number of atoms and ions, selected for lack of seriously disturbing blends. The selection was made without regard to any changes in wave length. The radial velocities determined from the individual lines are, of course, corrected to the sun and represent in each case the true velocity as determined from each individual line on each plate. These velocities are arranged in order of phase and are given individually, not only for the ten plates used in Table 3, but also for the remaining eight McDonald coudé spectrograms. For each atom or ion the mean radial velocity has been derived individually for each plate, together with the number of measures used in forming each mean. The mean velocities are plotted in Figures 1–5 as functions of the phase. The value of the period, 5.5 days, is indicated along the abscissae, so that the amount of repetition of each set of points can be clearly seen in all diagrams.

The velocity-curves fall into three distinct groups:

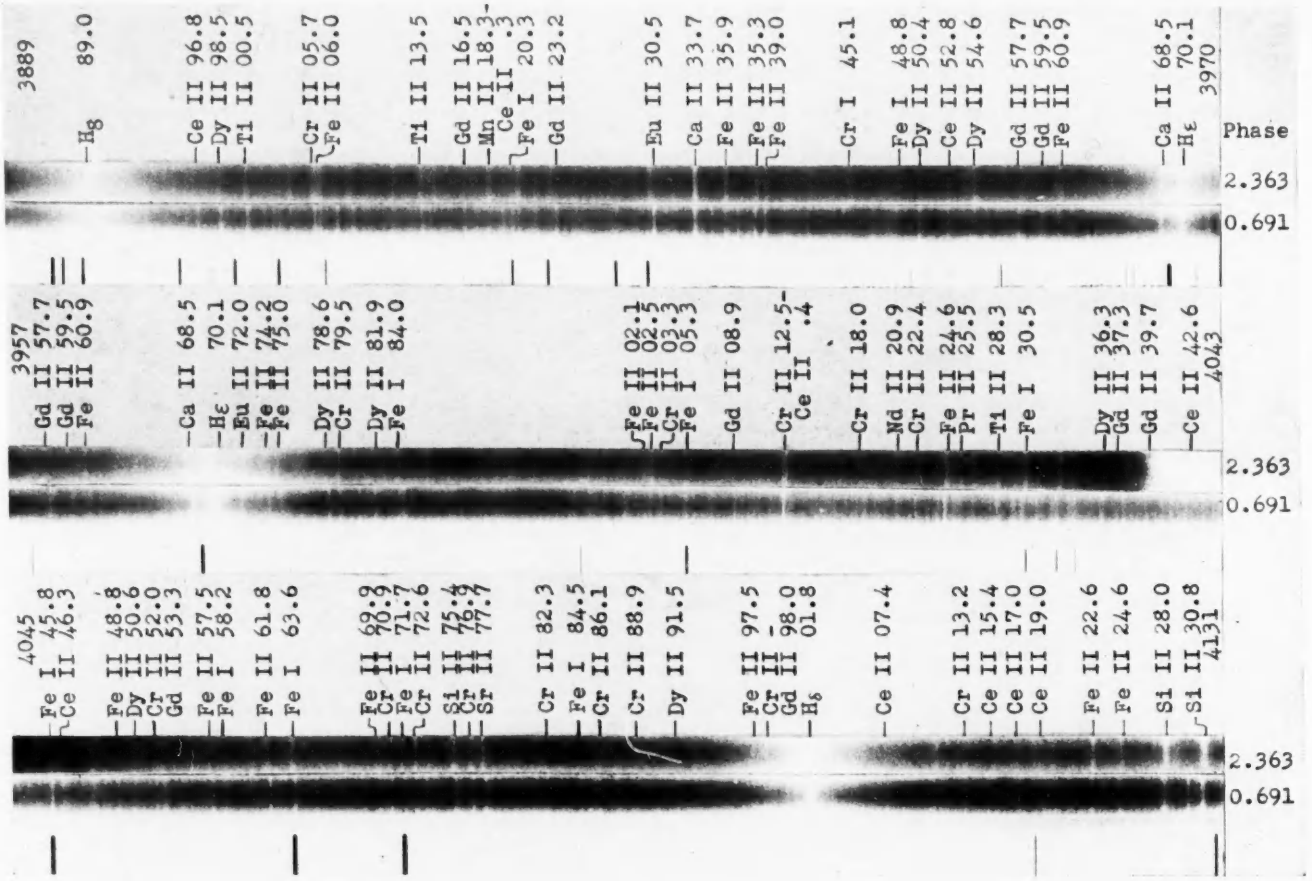
*a*) Lines which show a large range in velocity, with a pronounced minimum at phase 4.5 days after the epoch of maximum of *Eu* II intensity. Maximum velocity occurs at phase 1.5 days, and the curve is characterized by a sharp maximum and a shallow minimum. This type of variation is best determined for *Eu* II and *Dy* II. Probably all rare earths share in this type of variation, with the exception of *Ho* II, for which the material is inadequate. The following elements belong to group a: *Al* II, *Ca* I, *Mn* I, *Ni* I, *Ce* II, *Pr* II, *Nd* II, *Sm* II, *Eu* II, *Gd* II, *Dy* II, and perhaps *Sr* II. The range of the

[7] Russell, King, and Lang, *Phys. Rev.*, **52**, 456, 1937.

PLATE XXIII

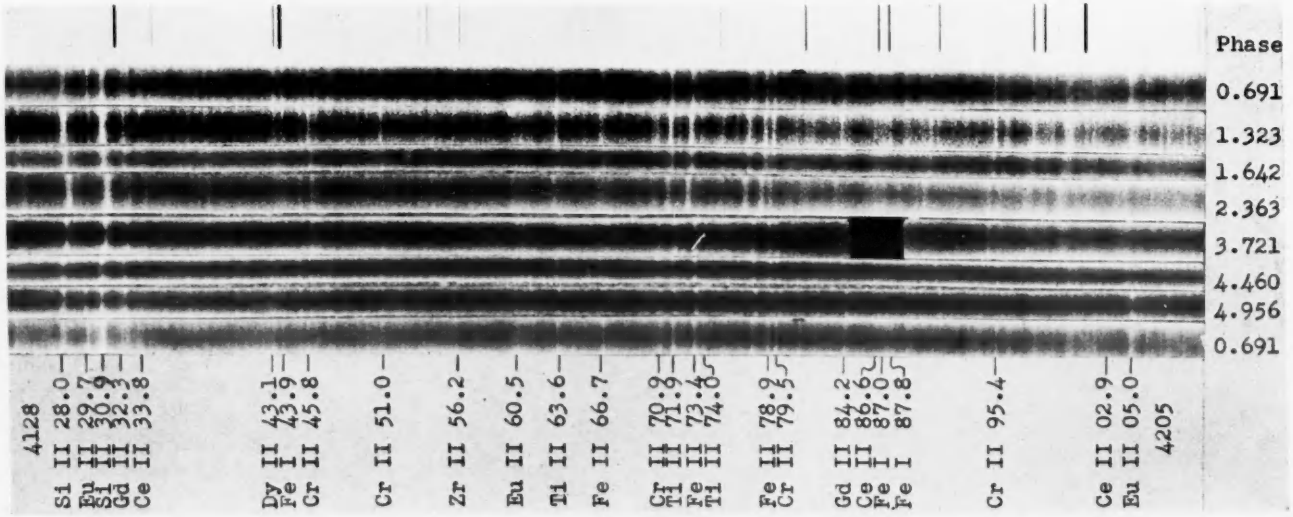
THE SPECTRUM OF $\alpha^2$ CANUM VENATICORUM

PLATE XXIV

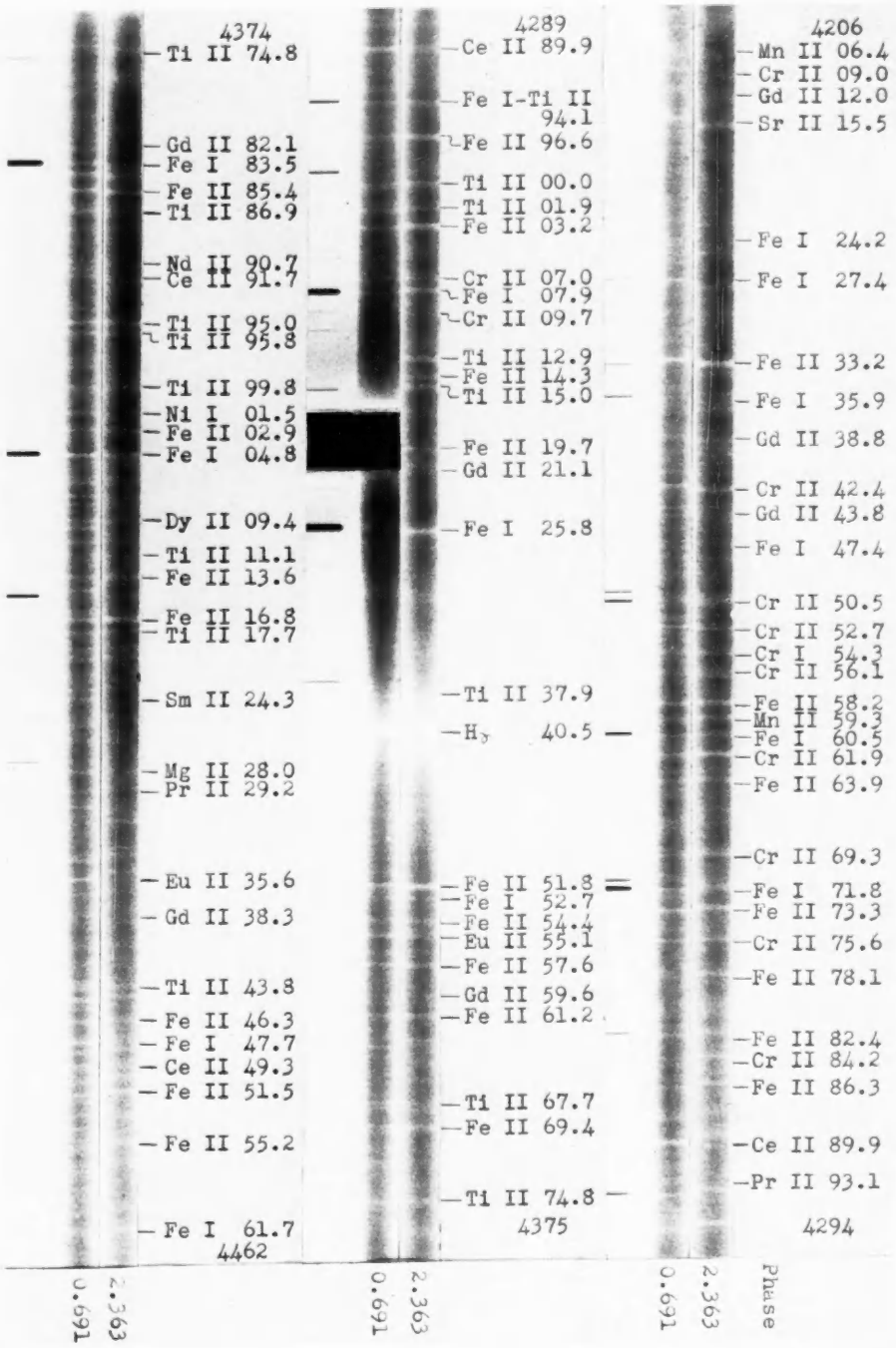


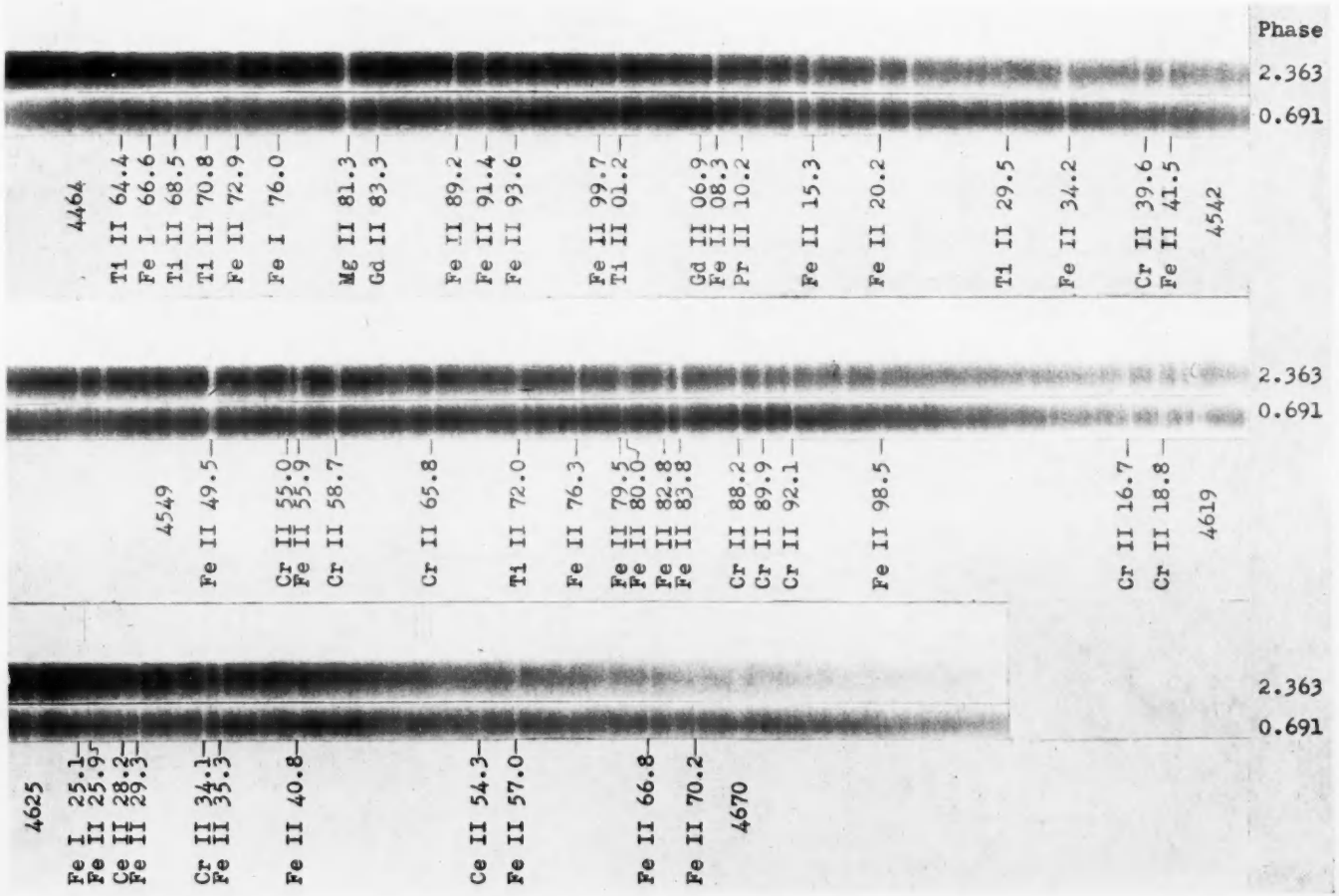

THE SPECTRUM OF $\alpha^2$ CANUM VENATICORUM

PLATE XXV



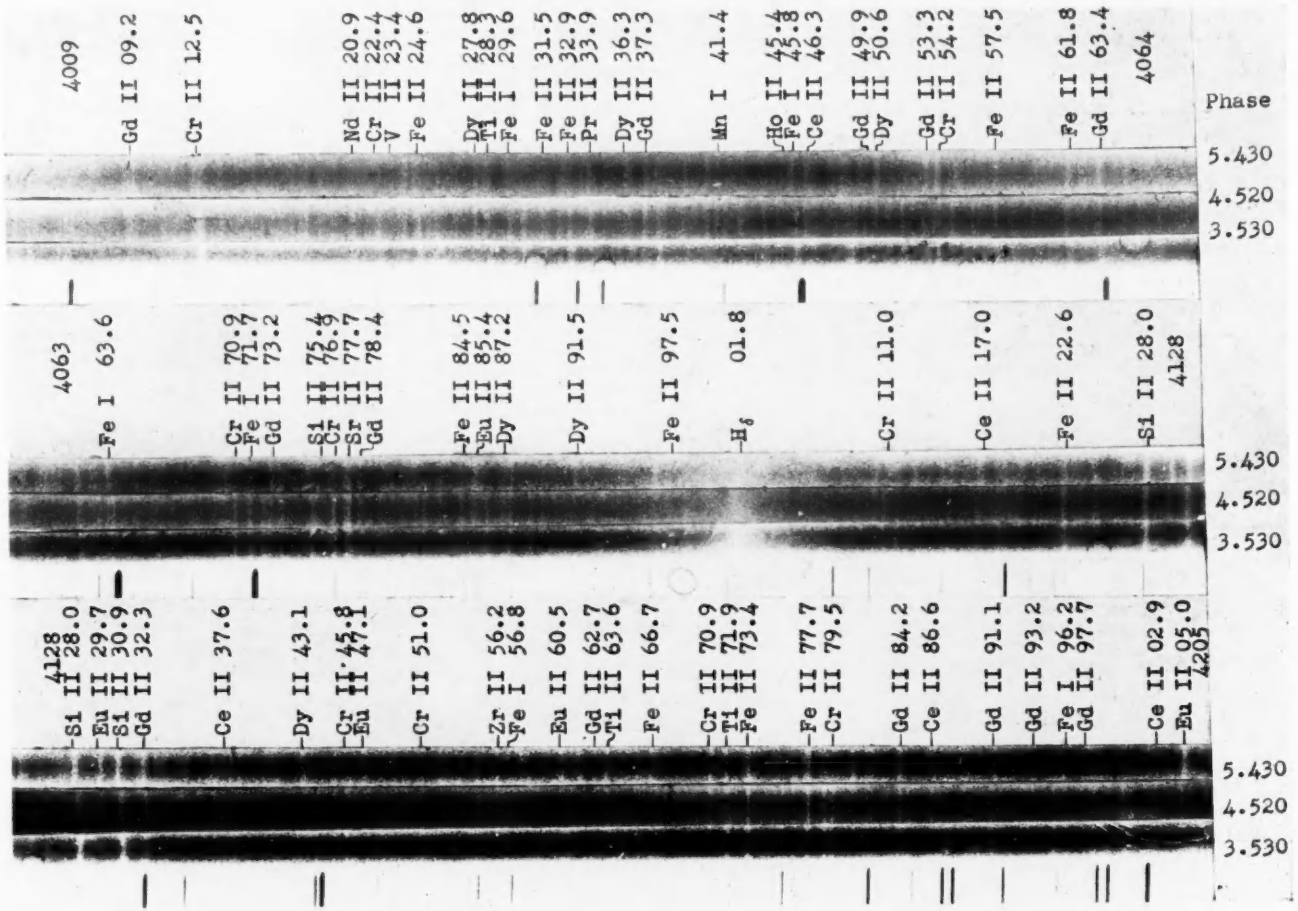

THE SPECTRUM OF $\alpha^2$ CANUM VENATICORUM


4374
Ti II 74.8
Gd II 82.1
Fe I 83.5
Fe II 85.4
Ti II 86.9
Nd II 90.7
Ce II 91.7
Ti II 95.0
Ti II 95.8
Ti II 99.8
Ni I 01.5
Fe II 02.9
Fe I 04.8
Dy II 09.4
Ti II 11.1
Fe II 13.6
Fe II 16.8
Ti II 17.7
Sm II 24.3
Mg II 28.0
Pr II 29.2
Eu II 35.6
Gd II 38.3
Ti II 43.8
Fe II 46.3
Fe I 47.7
Ce II 49.3
Fe II 51.5
Fe II 55.2
Fe I 61.7
4462
4289
Ce II 89.9
Fe I-Ti II 94.1
Fe II 96.6
Ti II 00.0
Ti II 01.9
Fe II 03.2
Cr II 07.0
Fe I 07.9
Cr II 09.7
Ti II 12.9
Fe II 14.3
Ti II 15.0
Fe II 19.7
Gd II 21.1
Fe I 25.8
Ti II 37.9
Hγ 40.5
Fe II 51.8
Fe I 52.7
Fe II 54.4
Eu II 55.1
Fe II 57.6
Gd II 59.6
Fe II 61.2
Ti II 67.7
Fe II 69.4
Ti II 74.8
4375
4206
Mn II 06.4
Cr II 09.0
Gd II 12.0
Sr II 15.5
Fe I 24.2
Fe I 27.4
Fe II 33.2
Fe I 35.9
Gd II 38.8
Cr II 42.4
Gd II 43.8
Fe I 47.4
Cr II 50.5
Cr II 52.7
Cr I 54.3
Cr II 56.1
Fe II 58.2
Mn II 59.3
Fe I 60.5
Cr II 61.9
Fe II 63.9
Cr II 69.3
Fe I 71.8
Fe II 73.3
Cr II 75.6
Fe II 78.1
Fe II 82.4
Cr II 84.2
Fe II 86.3
Ce II 89.9
Pr II 93.1
4294
0.691
2.363
Phase




THE SPECTRUM OF $\alpha^2$ CANUM VENATICORUM

PLATE XXVIII




THE SPECTRUM OF $\alpha^2$ CANUM VENATICORUM

PLATE XXIX

PLATE XXIX

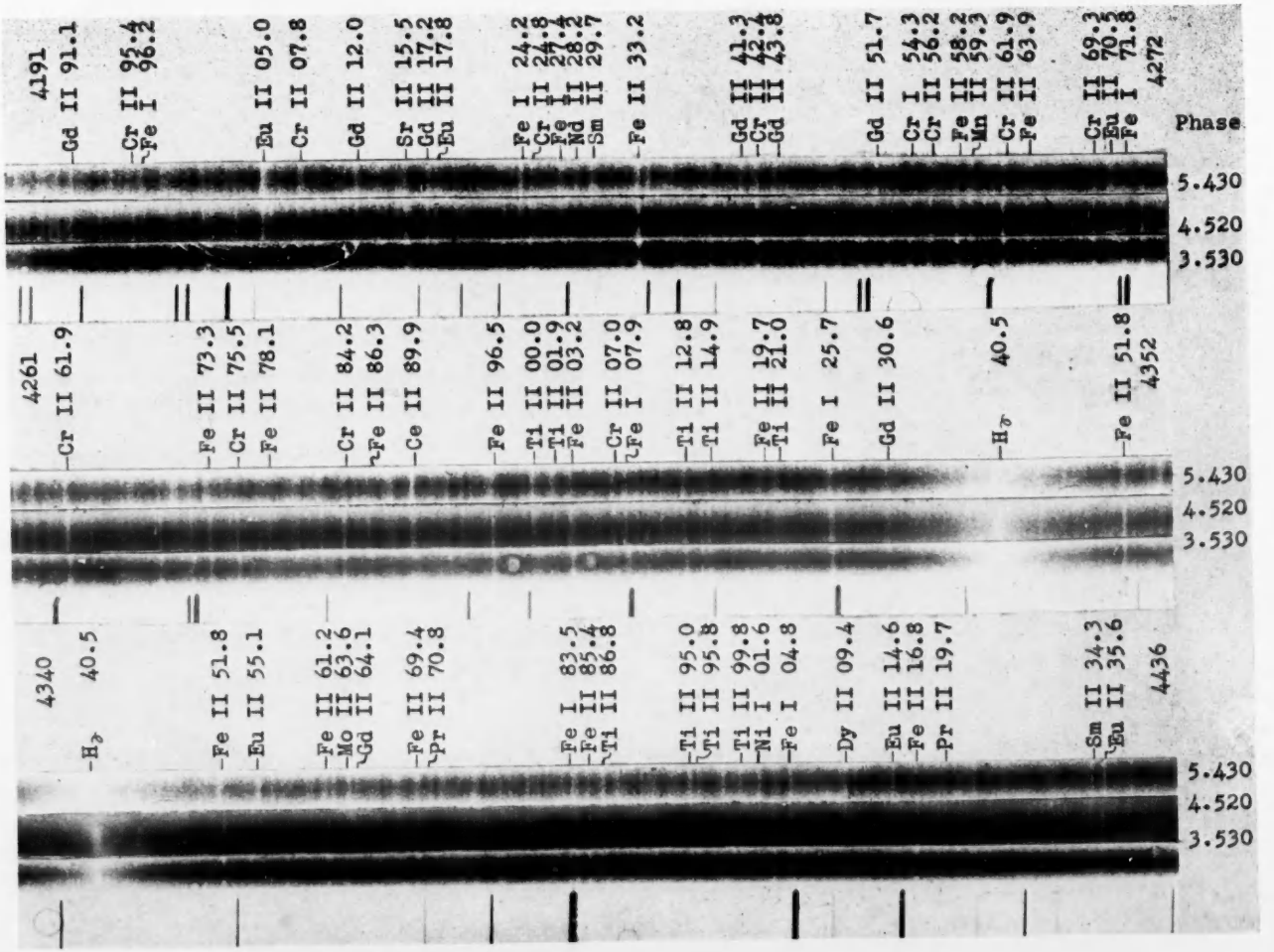

4191
Gd II 91.1
Cr II 95.4
Fe I 96.2
Eu II 05.0
Cr II 07.8
Gd II 12.0
Sr II 15.5
Gd II 17.2
Eu II 17.8
Fe I 24.2
Cr II 24.8
Fe I 27.4
Nd II 28.2
Sm II 29.7
Fe II 33.2
Gd II 41.3
Cr II 42.4
Gd II 43.8
Gd II 51.7
Cr I 54.3
Cr II 56.2
Fe II 58.2
Mn II 59.3
Cr II 61.9
Fe II 63.9
Cr II 69.3
Eu II 70.3
Fe I 71.8
4272
Phase
5.430
4.520
3.530
4261
Cr II 61.9
Fe II 73.3
Cr II 75.5
Fe II 78.1
Cr II 84.2
Fe II 86.3
Ce II 89.9
Fe II 96.5
Ti II 00.0
Ti II 01.9
Fe II 03.2
Cr II 07.0
Fe I 07.9
Ti II 12.8
Ti II 14.9
Fe II 19.7
Ti II 21.0
Fe I 25.7
Gd II 30.6
40.5
Fe II 51.8
4352
5.430
4.520
3.530
4340
40.5
Fe II 51.8
Eu II 55.1
Fe II 61.2
Mo II 63.6
Gd II 64.1
Fe II 69.4
Pr II 70.8
Fe I 83.5
Fe II 85.4
Ti II 86.8
Ti II 95.0
Ti II 95.8
Ti II 99.8
Ni I 01.6
Fe I 04.8
Dy II 09.4
Eu II 14.6
Fe II 16.8
Pr II 19.7
Sm II 34.3
Eu II 35.6
4436
5.430
4.520
3.530

PLATE XXX




THE SPECTRUM OF $\alpha^2$ CANUM VENATICORUM

TABLE 1

$\alpha^2$ CVn Region $\lambda < 3315$

| Wave Length and Int. | Principal Contributors | Rare Earths and Minor Contributors |
|---|---|---|
| 3087.94 (2) | Ti II 88.03 (500) Cr II 87.90 (20) | |
| 3089.17 (0) | Fe II 89.39 (4) Ti II 89.40 (100) | Sa III 88.7 (100) Yb II 89.09 (10) Gd II 89.20 (30) Gd II 89.25 (20) |
| 3089.86 (2) | Ti II 90.05 (100) Gd II 89.95 (400) | Fe II 90.04 (8) Cr II 89.75 (1) Eu II 89.64 (3) |
| 3091.49 (1) | Fe I 91.58 (300) (Eu II 91.29 (10)) | Gd II 91.46 (8) |
| 3093.64 (4nn) | Cr II 93.48 (40) Cr II 93.97 (15) | V II 93.11 (2500) Dy II 93.11 (60) Sa III 93.1 (20) Gd II 93.85 (25) |
| 3098.28 (1) | Cr II 98.16 (18) (Nd II 98.48 (50)) | Sa III 98.3 (80) Sa III 98.6 (250) |
| 3102.26 (2) | Cr II 02.30 (2) Cr II 02.58 (2) | V II 02.29 (2000) Gd II 02.55 (1000) Dy II 02.19 (70) |
| 3103.62 (1) | Cr II 03.48 (30) Ti II 03.80 (200) | Ce II 03.38 (125) Dy II 03.84 (60) Dy II 03.25 (60) |
| 3105.25 (1) | Fe II 05.55 (5) Fe II 05.17 (5) | Ti II 05.08 (100) Dy II 05.00 (40) Gd II 05.53 (80) Nd II 05.42 (30) |
| 3106.61 (1) | Fe II 06.56 (4) (Ti II 06.23 (150)) | Ce III 06.97 (200) Zr II 06.58 (35) |
| 3107.57 (2) | Cr II 07.58 (50) | |
| 3108.94 (1) | Cr II 08.66 (10) | |
| 3110.64 (2n) | V II 10.71 (1500) (Ti II 10.67 (100)) | Ce III 10.52 (200) Sa III 10.0 (150) Zr II 10.87 (8) |
| 3111.97 (1) | Cr II 11.95 (15) (Ce II 12.20 (S 15)) | Ti II 12.05 (70) Gd II 11.99 (20) Sa III 12.0 (20) |
| 3114.49 (2n) | Fe II 14.29 (7) Fe II 14.68 (4) | |
| 3115.56 (2) | Cr II 15.65 (20) Cr II 15.28 (12) | Fe II 15.49 (1) Fe II 15.35 (2) Sa III 15.6 (50) Gd II 15.77 (10) |
| 3116.84 (2) | Cr II 16.76 (20) Cr II 17.28 (15) | Fe II 16.59 (6) Sa III 16.9 (150) Gd II 17.01 (15) |
| 3118.70 (4n) | Cr II 18.65 (60) Cr II 18.14 (10) V II 18.38 (1000) | Gd II 18.60 (150) Gd III 18.0 (1000) Sm III 18.3 (40) Sm III 18.8 (80) FeII 18.30 (0) Fe II 18.71 (0) |
| 3120.06 (1) | Fe II 20.02 (1) (Ti II 19.80 (150)) | Dy II 20.18 (80) Gd II 19.94 (800) Gd II 20.18 (125) Nd II 19.75 (15) |
| 3120.58 (3) | Cr II 20.37 (75) | |
| 3121.44 (1) | Cr II 21.04 (8) Cr II 21.22 (2) | Ce III 21.55 (400) Ti II 21.60 (20) Pr II 21.57 (25) |
| 3122.00 (1) | Cr II 21.97 (7) Cr II 21.84 (10) | Ti II 22.06 (50) Gd II 21.76 (80) |
| 3122.74 (1) | Cr II 22.60 (30) | |
| 3125.11 (5) | Cr II 24.98 (100) Cr II 25.46 (7) | Cr II 25.02 (15) V II 25.28 (600) Sm III 24.9 (150) |
| 3126.30 (1) | Dy II 26.18 (50) (V II 26.21 (150)) | Zr II 25.92 (12) |

TABLE 1 -- Continued

| Wave Length and Int. | Principal Contributors | Rare Earths and Minor Contributors |
|---|---|---|
| 3127.93 (1) | Ti II 27.88 (35) Gd II 27.70 (100) | Ce II 27.53 (80) |
| 3128.87 (4) | Cr II 28.70 (40) Fe II 29.01 (1) Ti II 28.64 (70) | Dy II 28.41 (150) Gd II 28.56 (200) Sm III 29.0 (60) Zr II 29.16 (10) |
| 3130.10 (1) | V II 30.26 (100) (Zr II 29.76 (12)) | Gd II 29.95 (100) Gd II 29.70 (80) |
| 3130.71 (2) | Fe II 30.56 (2) Ti II 30.80 (100) | Cr II 30.55 (1) Gd II 30.81 (200) Eu II 30.73 (80) |
| 3132.08 (5) | Cr II 32.06 (125) Fe II 31.72 (4) | Sm III 31.6 (25) Sm III 32.5 (125) Eu II 32.16 (40) |
| 3133.42 (1) | Fe II 33.05 (4) (Fe II 33.72 (1)) | V II 33.33 (150) Nd II 33.60 (100) Zr II 33.49 (25) |
| 3134.36 (2) | Cr II 34.33 (25) (Eu II 34.69 (15)) | |
| 3135.65 (4) | Cr II 35.74 (30) Fe II 35.36 (9) | Cr II 35.35 (20) Dy II 35.37 (500) |
| 3136.70 (3) | Cr II 36.68 (40) (Eu II 36.96 (15)) | Pr II 36.79 (20) |
| 3137.44 (2) | Cr II 37.55 (8) Cr II 37.11 (3) | Nd II 37.25 (30) |
| 3138.40 (1) | Cr II 38.25 (7) Fe II 38.21 (1n) | Zr II 38.66 (25) |
| 3140.06 (4) | Cr II 39.91 (8) (Gd II 39.72(15)) | |
| 3140.34 (4) | Cr II 40.21 (25) Fe II 40.69 (1) | Dy II 40.64 (150) Eu II 40.36 (15) |
| 3141.43 (1) | Cr II 41.80 (4) Ce III 41.25 (250) | Dy II 41.13 (200) Nd II 41.48 (40) |
| 3142.21 (1) | Fe II 42.22 (0) V II 42.48 (150) | Fe I 42.45 (125) Dy II 42.30 (40) Ce II 42.31 (25) Nd II 42.44 (30) |
| 3142.91 (1) | Cr II 42.74 (10) Cr II 42.97 (8) | Gd II 42.90 (300) Fe I 42.88 (80) |
| 3143.15 (1) | Gd II 43.13 (400) (Fe I 43.24 (60)) | |
| 3145.03 (2) | Cr II 45.10 (10) Fe II 44.75 (5) | Gd II 45.00 (2500) Ce II 45.28 (150) Ce III 43.96 (200) Sa III 45.1 (30) |
| 3145.96 (1) | Cr II 45.77 (15) Gd II 45.52 (800) | |
| 3147.35 (4n) | Cr II 47.23 (50) Ce III 47.05 (300) | Pr III 47.0 (60) Pr III 47.7 (100) Gd II 46.88 (250) Eu II 47.43 (20) Dy II 47.53 (30) |
| 3149.33 (1n?) | Cr II 49.12 (4) Sm III 49.4 (20) | Sm III 49.7 (100) Nd II 49.30 (40) Nd II 49.51 (40) |
| 3150.20 (3) | Cr II 50.11 (20) Cr II 49.83 (20) | Eu II 49.88 (60) |
| 3151.32 (1) | Fe I 51.35 (300) (V II 51.32 (100)) | Tm II 51.04 (200) Pr II 51.54 (25) |
| 3152.25 (3) | Cr II 52.21 (40) Ti II 52.25 (125) | Sm II 52.52 (300) Gd II 51.91 (20) Dy II 51.89 (50) |
| 3154.33 (5) | Fe II 54.20 (12) Cr II 54.04 (5) | Cr II 54.10 (2) Ti II 54.19 (100) |
| 3155.91 (1) | Fe II 55.95 (2) Ti II 55.67 (125) | Nd III 56.0 (10) Ce II 55.70 (20) Zr II 55.68 (10) Nd II 55.76 (10) |
| 3158.11 (1) | Cr II 58.03 (20) | |
| 3159.13 (2) | Cr II 59.10 (5) (Fe II 59.32 (pr)) | Zr II 59.12 (5) Nd II 59.22 (10) |

TABLE 1 -- Continued

| Wave Length and Int. | Principal Contributors | Rare Earths and Minor Contributors |
|---|---|---|
| 3160.18 (1) | Cr II 59.86 (5) Cr II 60.11 (3) | Dy II 60.50 (40) Eu II 60.33 (10) Pr III 60.0 (150) |
| 3161.41 (1) | Gd II 61.37 (2500) Ti II 61.20 (125) | Ti II 61.77 (150) |
| 3162.19 (1) | Cr II 62.46 (10) Fe II 61.94 (5) | Ti II 62.57 (200) Fe I 61.95 (200) |
| 3163.13 (1) | Fe II 62.80 (8) Fe II 63.09 (5) | Nd III 63.3 (10) |
| 3164.12 (2) | Cr II 63.93 (10) Cr II 64.28 (4) | Cr II 64.48 (1) Ce II 64.15 (200) Zr II 64.32 (20) |
| 3165.54 (1) | Ce III 65.54 (25) Sm III 65.5 (150) | Zr II 65.45 (7) Zr II 65.98 (10) |
| 3166.48 (2) | Fe II 66.67 (4) (Fe II 66.22 (pr)) | Eu II 66.49 (25) Zr II 66.29 (8) |
| 3168.03 (3) | Fe II 67.85 (11) (Cr II 68.39 (2)) | Sm III 68.0 (50) Sm III 68.2 (80) Ce III 68.02 (25) Gd II 68.13 (50) Gd II 68.29 (60) |
| 3168.86 (1) | Cr II 69.20 (25) Ti II 68.52 (300) | Ce II 69.18 (150) Yb II 69.06 (10) |
| 3170.22 (1) | Fe II 70.34 (6) (Cr II 69.85 (2)) | Dy II 69.98 (300) Eu II 70.41 (50) Sm II 69.87 (250) Pr III 70.2 (50) |
| 3172.13 (2) | Cr II 72.08 (40) (Nd III 71.7 (40)) | Eu II 71.94 (50) Pr II 72.31 (50) Gd II 72.17 (30) |
| 3172.92 (1) | Tm II 72.83 (180) Pr III 72.9 (100) | Gd II 72.86 (40) |
| 3173.71 (1) | Cr II 73.58 (15) Eu II 73.61 (100) | |
| 3175.33 (2) | Fe II 75.08 (4) Fe I 75.45 (200) | Ti II 75.66 (20) |
| 3177.70 (3) | Fe II 77.53 (10) (Cr II 77.90 (1)) | Dy II 77.88 (125) Gd II 77.49 (30) |
| 3178.72 (1) | Cr II 78.79 (7) (Ti II 78.63 (25)) | Eu II 78.71 (12) Gd II 78.94 (12) |
| 3179.51 (2) | Fe II 79.50 (8) Cr II 79.45 (8) | |
| 3180.18 (1) | Fe II 80.16 (7) Fe I 80.23 (300) | Ti II 80.22 (20) Gd II 80.03 (10) |
| 3180.80 (2) | Cr II 80.73 (75) | |
| 3181.54 (2) | Cr II 81.43 (20) (Zr II 81.58 (8)) | |
| 3182.04 (1) | Ti II 81.84 (50) Fe I 82.06 (80) | Zr II 81.94 (7) |
| 3182.73 (1) | Fe I 82.97 (125) (Fe II 83.11 (8)) | Ti II 82.57 (40) Zr II 82.86 (35) Gd II 82.55 (60) Eu II 82.98 (12) |
| 3183.56 (4) | Cr II 83.32 (40) Ce II 83.52 (250) | Eu III 83.7 (100) Sm II 83.92 (400) |
| 3184.52 (2) | Cr II 84.36 (15) Pr III 84.8 (150) | Dy II 84.78 (40) |
| 3185.30 (1) | Fe II 85.31 (5) Eu II 85.54 (70) | Sm III 85.6 (10) |
| 3186.74 (5) | Fe II 86.74 (11) Cr II 86.75 (18) | Sm II 87.01 (200) Dy II 86.37 (80) |
| 3187.59 (1) | Fe II 87.29 (8) V II 87.72 (200) | Sm II 87.22 (300) Sm II 87.79 (200) Dy II 87.68 (60) He I 87.74 (200) |
| 3188.75 (1) | Fe I 88.57 (150) Fe I 88.82 (150) | V II 88.52 (300) |
| 3190.75 (3) | Cr II 90.69 (6) Ti II 90.87 (200) | V II 90.68 (150) Fe II 90.84 (pr) Eu II 90.60 (15) |
| 3192.00 (1) | Fe II 92.06 (3) Pr III 91.8 (60) | Ti I 91.99 (100) Zr II 91.93 (12) |

TABLE 1 -- Continued

| Wave Length and Int. | Principal Contributors | Rare Earths and Minor Contributors |
|---|---|---|
| 3193.00 (1) | Fe II 92.92 (9) Sm II 93.01 (300) | Cr II 93.41 (2) Gd II 93.17 (200) Dy II 93.31 (80) Yb II 92.88 (50) |
| 3193.96 (3) | Fe II 93.81 (11) | |
| 3194.81 (1) | Cr II 94.63 (10) Ce II 94.82 (200) | Ti II 94.76 (40) Eu II 95.10 (10) Sm III 94.8 (15) Sm III 95.0 (15) |
| 3196.14 (4) | Fe II 96.07 (10) (Sm II 96.18 (150)) | Pr II 96.04 (50) |
| 3197.08 (4) | Cr II 97.12 (75) Cr II 96.96 (20) | Fe I 96.93 (500) Sm III 96.7 (15) Sm III 97.2 (10) Nd III 96.7 (20) |
| 3198.62 (1) | (Eu II 98.76 (20)) (Yb (II?) 98.64 (S 20) ) | |
| 3199.91 (1n) | Cr II 99.87 (10) Cr II 00.45 (10) | Fe I 99.52 (300) Ti I 99.91 (200) Sm III 99.6 (50) Gd II 00.31 (50) |
| 3201.45 (1) | Cr II 01.26 (25) Ce II 01.71 (300) | Nd III 01.5 (40) Yb II 01.16 (25) |
| 3202.60 (1) | Cr II 02.52 (15) Ti II 02.54 (200) | |
| 3203.53 (1) | Cr II 03.53 (15) Fe II 03.51 (1) | Fe II 03.74 (0) Ti II 03.43 (15) Nd II 03.46 (30) |
| 3205.14 (3) | Cr II 05.11 (25) Fe I 05.40 (300) | Sm III 05.4 (20) |
| 3206.32 (1) | Gd II 06.47 (400) Dy II 06.40 (80) | Fe II 06.21 (0) Ti II 05.99 (15) |
| 3207.22 (1) | Sm II 07.18 (400) Dy II 07.10 (60) | Eu II 07.31 (20) |
| 3208.67 (2) | Cr II 08.62 (20) Dy II 08.81 (80) | Ti II 08.61 (20) |
| 3209.42 (2) | Cr II 09.21 (50) Fe II 09.60 (1) | Fe I 09.30 (200) Sm III 09.3 (40) Gd II 09.66 (60) |
| 3210.49 (1) | Fe II 10.45 (10) (Eu II 10.16 (10)) | |
| 3211.89 (1) | Cr II 11.50 (3) Sm II 11.73 (400) | Gd II 11.57 (50) Fe I 11.99 (70) |
| 3213.30 (3) | Fe II 13.31 (13) Cr II 12.91 (18) | Cr II 13.46 (3) |
| 3214.74 (1) | V II 14.75 (120) Ti II 14.75 (80) | Sm III 14.9 (20) |
| 3215.69 (1) | Fe I 15.94 (300) (Dy II 15.19 (125)) | |
| 3216.62 (3) | Cr II 16.55 (20) (Sm II 16.85 (300) | Dy II 16.63 (150) Y II 16.68 (70) |
| 3217.28 (3) | Cr II 17.44 (50) V II 17.12 (400) | Ti II 17.06 (150) Sm III 17.5 (30) Gd II 17.03 (25) Gd II 17.13 (40) Nd II 17.12 (25) |
| 3218.85 (1) | Ce II 18.94 (200) Sm II 18.60 (300) | Zr II 18.52 (7) |
| 3219.48 (2) | Cr II 19.79 (10) Cr II 19.13 (18) | Fe I 19.58 (200) Pr II 19.55 (75) Gd II 19.25 (15) |
| 3220.91 (1n) | Fe II 20.83 (0) Ce II 21.17 (250) | Sm III 21.2 (40) |
| 3222.99 (3) | Fe II 23.44 (1) Ti II 22.84 (150) | Fe II 22.94 (0) Sm III 22.7 (100) Dy II 23.29 (80) |
| 3224.20 (1) | Ti II 24.24 (150) Gd II 23.74 (1000) | |
| 3225.66 (2) | Cr II 25.44 (8) Cr II 25.39 (12) | Fe I 25.79 (300) Gd II 25.46 (600) Sm III 25.4 (50) Dy II 25.96 (80) |

TABLE 1 -- Continued

| Wave Length and Int. | Principal Contributors | Rare Earths and Minor Contributors |
|---|---|---|
| 3226.61 (1) | Fe II 26.38 (2) Cr II 26.36 (4) | Gd II 26.32 (1000) Ti II 26.77 (35) |
| 3227.73 (3) | Fe II 27.73 (13) (Cr II 27.48 (3)) | Sm III 27.5 (25) Nd II 28.05 (20) |
| 3228.72 (1) | Fe II 28.60 (3) Ti II 28.60 (100) | Sm II 28.78 (200) Ce III 28.56 (400) Sm III 29.1 (80) Zr II 28.81 (15) Gd II 28.64 (15) |
| 3229.58 (2) | Cr II 29.89 (10) Cr II 29.38 (8) | Ti II 29.42 (70) Ti II 29.19 (60) Nd III 29.9 (300) Pr III 29.2 (30) Gd II 29.32 (25) Ce II 29.36 (25) |
| 3230.54 (1) | Fe II 30.50 (1) Sm II 30.56 (400) | |
| 3231.78 (3) | Fe II 31.70 (5) Cr II 31.64 (8) | Zr II 31.69 (30) Eu II 31.87 (10) |
| 3232.15 (1) | Ti II 32.28 (100) Fe II 32.05 (0) | Eu II 32.31 (20) |
| 3233.08 (3) | Fe II 32.79 (7) (Fe I 33.05 (100)) | Gd II 32.95 (80) Gd II 32.70 (50) |
| 3234.28 (3n) | Cr II 34.06 (50) Ti II 34.52 (500) | Ce II 34.27 (300) Ce II 34.16 (300) Eu II 34.31 (15) Pr II 34.22 (20) |
| 3236.60 (2) | Ti II 36.57 (300) Sm II 36.64 (500) | Ce II 36.73 (150) Fe II 36.85 (0) Dy II 36.63 (40) |
| 3237.77 (2) | Fe II 37.81 (8) Fe II 37.40 (5) | V II 37.88 (350) Gd II 37.62 (100) Nd III 37.7 (200) Eu II 37.37 (15) Nd II 37.91 (20) |
| 3238.95 (2) | Cr II 38.77 (50) Ti II 39.04 (300) | Gd II 38.62 (300) Pr II 38.87 (15) |
| 3239.49 (1) | Fe I 39.44 (400) Ti II 39.66 (80) | |
| 3239.99 (1) | Cr II 40.07 (7) Sm II 39.66 (300) | Fe II 39.87 (pr) Tm II 40.23 (125) Eu II 40.11 (10) |
| 3241.87 (2) | Fe II 41.68 (2) Ti II 41.99 (300) | Y II 42.28 (100) Sm III 42.3 (20) Sm III 42.6 (50) Sm II 41.59 (100) Tm II 41.53 (180) |
| 3243.69 (2) | Fe II 43.72 (8) Ce II 43.37 (200) | |
| 3244.03 (1) | Fe I 44.19 (300) (Eu II 44.21 (8)) | Eu II 44.47 (12) |
| 3245.67 (1) | Fe I 45.98 (200) Cr II 45.31 (5) | Pr II 45.46 (25) |
| 3247.45 (4) | Fe II 47.17 (9) Fe II 47.39 (3) | Cr II 47.33 (8) Sm III 47.17 (400) Nd III 47.1 (30) Eu II 47.32 (30) |
| 3248.64 (1) | Ti II 48.60 (200) (Gd II 48.46 (25)) | |
| 3249.77 (2) | Fe II 49.66 (4) Fe II 49.91 (1) | Cr II 49.52 (3) Nd III 49.4 (80) Gd II 50.19 (300) Gd II 49.75 (40) |
| 3251.73 (1n) | Ti II 51.91 (150) Fe II 51.34 (2) | V II 51.87 (200) Dy II 51.26 (300) Dy II 51.90 (50) Dy II 52.19 (50) Eu II 51.44 (20) |
| 3252.94 (1) | Ti II 52.91 (200) Cr II 52.50 (5) | Gd II 52.74 (30) |
| 3254.47 (2) | Ti II 54.25 (125) Fe I 54.36 (200) | V II 54.77 (300) Sm II 54.38 (500) Nd III 54.7 (250) Lu II 54.32 (90) |
| 3256.02 (2) | Fe II 55.88 (8) Dy II 56.20 (80) | Nd III 56.4 (40) Gd II 55.82 (150) Gd II 56.38 (80) |

TABLE 1 -- Continued

| Wave Length and Int. | Principal Contributors | Rare Earths and Minor Contributors |
|---|---|---|
| 3257.08 (1) | Fe II 57.36 (1) Gd II 57.07 (100) | Nd II 56.90 (15) |
| 3257.97 (2) | Fe II 57.89 (3) Cr II 58.01 (3) | V II 57.89 (100) Tm II 58.05 (150) |
| 3258.98 (3) | Fe II 59.05 (10) Fe II 58.77 (10) | Cr II 58.77 (30) Gd II 59.25 (250)<br>Eu II 58.68 (20) Nd II 59.23 (30) |
| 3260.57 (1) | (Ti II 60.26 (30))<br>(Ce II 60.97 (60)) | Dy II 60.69 (50) Nd III 60.9 (15)<br>Nd II 60.66 (20) |
| 3261.45 (2) | Ti II 61.60 (300) Cr II 61.56 (4) | Fe II 61.51 (1) Sm III 61.2 (50)<br>Nd III 61.3 (400) Yb II 61.51 (10) |
| 3262.01 (3) | Cr II 61.89 (0) Fe I 62.28 (50) | Nd III 62.3 (300) Sm II 62.26 (...) |
| 3263.80 (1) | Ti II 63.69 (70) | |
| 3264.49 (2) | Cr II 64.26 (35) | |
| 3266.94 (2) | Fe II 66.94 (4) Fe II 67.03 (3) | Eu II 66.39 (200) Gd II 67.08 (10)<br>Nd II 67.25 (30) |
| 3268.73 (1n) | Cr II 68.48 (10) Cr II 69.11 (10) | Fe II 68.51 (3) Fe II 68.92 (pr)<br>Dy II 69.12 (80) |
| 3270.24 (1) | Cr II 70.14 (40) (GdII 70.51 (100)) | |
| 3271.59 (1) | Ti II 71.65 (125) V II 71.12 (1200) | Cr II 71.40 (0) |
| 3272.04 (1) | Ti II 72.08 (100) Ce II 72.25 (250) | Zr II 72.21 (8) |
| 3273.34 (1) | Fe II 73.50 (3) Cr II 73.20 (1) | Zr II 73.04 (75) Sm II 73.48 (500)<br>Nd III 73.2 (25) Gd II 73.16 (12) |
| 3276.55 (1) | Fe II 76.61 (5) Cr II 76.28 (1) | V II 76.12 (1500) Ce II 76.25 (18) |
| 3278.81 (1) | Cr II 78.79 (2) Ti II 78.92 (150) | Sm III 78.7 (20) |
| 3280.85 (1) | Pr III 81.0 (200) (Zr II 80.75 (3) | |
| 3281.72 (1n) | Fe II 81.29 (7) Ti II 82.33 (150) | Gd II 81.61 (200) Gd II 82.30 (400)<br>Sm III 81.6 (25) Nd III 81.7 (10)<br>Nd III 82.1 (20) |
| 3283.07 (1) | Cr II 83.04 (20) (Zr II 82.84 (12)) | Dy II 82.79 (100) Nd II 82.78 (8) |
| 3284.17 (1) | (Ce II 84.22 (20)) (Eu II 83.87 (10)) | Nd III 83.6 (200) |
| 3285.60 (1) | Cr II 85.96 (20) Fe II 85.42 (3) | Sm II 85.66 (200) Eu II 85.88 (12) |
| 3288.03 (2) | Cr II 88.04 (15) Ti II 87.65 (200) | Sm III 88.1 (40) Dy II 87.95 (50)<br>Nd III 87.4 (60) Nd III 88.0 (15) |
| 3291.76 (2) | Cr II 91.75 (40) (Gd II 92.21 (800)) | Nd III 91.4 (15) |
| 3295.44 (4) | Cr II 95.43 (50) Fe II 95.24 (4) | Fe II 95.81 (6) Ce II 95.29 (80)<br>Pr III 96.1 (250) Pr II 95.53 (15) |
| 3298.04 (1) | Fe II 97.89 (5) Sm II 98.10 (500) | Eu II 98.30 (25) Dy II 97.61 (20) |
| 3299.97 (1) | Fe II 99.77 (1) (Fe II 00.06 (tr)) | Ce II 00.15 (60) Nd II 00.15 (70) |
| 3301.41 (1) | Cr II 01.21 (18) (Sm II 01.68 (100)) | Nd III 02.0 (40) |
| 3303.17 (1) | Fe II 02.86 (4) Fe II 03.47 (4) | Cr II 02.93 (1) |

TABLE 1 -- Continued

| Wave Length and Int. | Principal Contributors | Rare Earths and Minor Contributors |
|---|---|---|
| 3304.83 (1) | Cr II 04.73 (5) (Zr II 05.15 (15)) | Ce II 04.84 (60) Sm II 05.18 (200) Nd II 04.65 (10) |
| 3306.86 (1) | Cr II 06.95 (50) Cr II 07.04 (50) | Sm II 07.02 (500) |
| 3308.03 (1) | Cr II 08.15 (18) (Fe II 08.14 (tr)) | Eu II 08.02 (200) |
| 3309.16 (1) | Ti II 08.81 (100) (Nd III 09.15 (150)) | Dy II 08.89 (200) |
| 3310.69 (1) | Cr II 10.65 (35) (Sm II 10.66 (500)) | Eu II 10.80 (10) Tm II 10.59 (60) Nd II 10.36 (15) Nd II 10.90 (30) |
| 3312.19 (3) | Cr II 12.18 (40) Cr II 11.93 (40) | Ce II 12.21 (50) Eu II 12.15 (10) |
| 3313.69 (1) | Gd II 13.73 (600) Eu II 13.33 (400) | Gd II 13.37 (80) Zr II 13.70 (8) |
| 3314.36 (1) | Cr II 14.57 (35) Cr II 14.06 (18) | Sm III 14.9 (40) Ce II 14.72 (100) Zr II 14.49 (10) Pr II 14.38 (12) |

TABLE 2

$\alpha^2$ CVn. Region λ 3317 - λ 3408

| Phase 0.47 | 1.46 | 2.93 | 3.94 | 4.93 | Identification |
|---|---|---|---|---|---|
| | | | | 3317.39 (1) | (Dy II 7.12 (40)) (Eu II 7.35 (8)) |
| | | | | 3318.00 (2) | Ti II 8.02 (125) Ce II 7.80 (30) Gd II 8.06 (100) |
| | | | | 3318.96 (1) | Fe II 8.86 (0) (Zr II 9.03 (8)) |
| | | | | 3320.03 ($2^+$) | Gd II 0.44 (300) Eu 9.89 (80) Dy II 9.89 (400) Sm II 0.15 (600) (Gd II 0.32 (20)) (Gd II 9.83 (15)) |
| | | | | 3320.87 (1) | Sm II 1.12 (800) (Ce II 0.94 (10)) (Ce II 0.79 (8)) |
| 3321.46 (2) | 1.61 (2) | | | 1.83 (3) | Fe II 1.49 (1) Ti II 1.70 (125) Eu II 1.86 (100) (V II 1.54 (150)) (Nd III 1.9 (30)) |
| 3322.95 (3) | 2.97 (3) | | | 3.04 (5) | Fe II 3.07 (8) Ti II 2.94 (300) Cr II 2.69 (12) Cr II 3.53 (8) (Sm III 2.7 (30)) (Zr II 2.99 (10)) |
| 3324.21 (2) | 4.13 (3) | | | 4.26 (2) | Cr II 4.35 (50) Cr II 4.06 (25) Cr II 4.10 (20) (Sm III 4.3 (5)) |
| 3325.31 (1) | 5.33 (1) | | | 5.38 (2) | Fe II 5.01 (1) Fe I 5.46 (100) Ce II 5.33 (50) Sm II 5.26 (300) Sm III 5.3 (100) |
| 3326.22 (1) | | | | 6.40 (1) | Dy II 6.19 (50) |

TABLE 2 -- Continued

| Phase 0.47 | 1.46 | 2.93 | 3.94 | 4.93 | Identification |
|---|---|---|---|---|---|
| 3326.91 (3) | 6.73 (2n) | | | 7.06 (4) | Ti II 6.76 (125) Nd III 7.2 (100) Dy II 7.08 (30) (Zr II 6.81 (15)) (Sm III 6.7 (20)) (Eu II 7.08 (8)) |
| | 7.54 (1?) | | | | (Fe II 7.63 (pr)) (Y II 7.87 (60)) |
| 3328.10 (3) | 8.30 (2) | | | 8.13 (1) | Cr II 8.35 (20) (Eu II 8.05 (15)) (Nd II 8.27 (80)) (Gd II 7.89 (10)) |
| 3329.23 (3) | 9.24 (2) | | | 9.41 (4) | Ti II 9.46 (200) Fe II 9.07 (2) Cr II 9.45 (4) Gd II 9.34 (400) |
| 3330.70 (1) | 0.73 (1) | | | 0.66 (1) | (Gd II 0.34 (800)) |
| 3331.28 (1) | | | | 1.37 (1) | Gd II 1.38 (4000) (Eu II 1.21 (15)) (Nd II 1.57 (40)) (Ce II 1.22 (10)) |
| 3332.06 (2) | 1.97 (2) | | | 2.11 (3) | Ti II 2.11 (125) Gd II 2.13 (1000) (Cr II 2.14 (0)) |
| 3333.09 (1) | 3.12 (1) | | | 2.91 (2) | Sm III 3.0 (60) Gd II 3.21 (40) Si II 3.16 (2) |
| 3334.01 (1) | 4.10 (1) | | | 4.21 (1) | Fe I 4.22 (150) Ce II 4.45 (60) Gd II 4.06 (150) Dy II 4.14 (30) (Zr II 4.25 (10)) (Nd II 4.47 (50)) |
| 3335.21 (4) | 5.21 (4) | | | 5.19 (5) | Cr II 5.28 (40) Cr II 5.46 (30) Ti II 5.19 (150) |
| 3336.13 (3) | 6.16 (2) | | | 6.33 (5) | Cr II 6.33 (40) Gd II 6.18 (2500) Sm II 6.12 (200) (Cr II 5.93 (4)) (Cr II 6.16 (2)) (Eu II 6.51 (15)) |
| 3337.34 (1) | 7.35 (1) | | | 7.43 (1) | Fe I 7.67 (125) La II 7.49 (800) (Eu II 7.59 (8)) |
| 3338.49 (1) | 8.67 (1) | | | 8.74 (1) | Fe II 8.52 (3) Eu 8.75 (80) (Zr II 8.41 (10)) (Nd II 9.06 (60)) |
| 3339.64 (3) | 9.50 (2) | | | 9.74 (5) | Cr II 9.80 (50) Cr II 9.90 (20) Si II 9.84 (3) Dy II 9.51 (50) (Nd III 9.6 (80)) (Nd III 9.9 (60)) |
| 3340.49 (2) | 0.38 (1) | | | 0.50 (3) | Ti II 0.34 (100) Fe I 0.57 (125) Sm II 0.58 (800) (Zr II 0.55 (15)) |
| 3341.81 (3) | 1.53 (3) | | | 1.74 (4) | Ti II 1.87 (300) Cr II 1.98 (5) Ce II 1.87 (100) Pr III 1.3 (1200) Dy II 1.88 (80) (Dy II 1.43 (40)) (Nd III 1.9 (40)) |
| 3342.60 (2) | 2.41 (2) | | | 2.55 (1) | Cr II 2.51 (50) (Sm II 2.35 (200)) (Sm III 2.7 (40)) |
| 3343.39 (1) | | | | 3.57 (2) | Sm II 3.49 (200) (Nd III 3.35 (60)) |
| 3344.03 (1) | 3.84 (1) | | | | Ti II 3.77 (70) Ce II 3.86 (200) (Zr II 3.81 (15)) |
| 3344.80 (1) | 4.63 (1) | | | | Ce II 4.76 (300) La II 4.56 (300) (Sm III 5.0 (30)) (Cr II 4.52 (1)) (Zr II 4.80 (15)) |
| 3345.62 (1) | 5.62 (1) | | | 5.87 (1) | Gd II 5.98 (2000) (Gd II 5.41 (100)) (Gd II 5.82 (80)) |

TABLE 2 -- Continued

| Phase 0.47 | 1.46 | 2.93 | 3.94 | 4.93 | Identification |
|---|---|---|---|---|---|
| 3346.80 (3) | 6.58 (2) | | | 6.85 (3) | Ti II 6.73 (60) (Eu II 6.63 (20)) |
| 3347.81 (3) | 7.78 (2) | | | 7.83 (3) | Cr II 7.84 (40) Dy II 7.82 (40) (Sm III 7.9 (30)) (Nd II 8.16 (25)) (Nd II 7.57 (10)) |
| 3348.88 (3) | 8.82 (3) | | | 8.88 (4) | Ti II 9.03 (800) (Sm II 8.68 (200)) |
| 3349.41 (3) | 9.47 (4) | | | 9.32 (4) | Ti II 9.41 (400) Cr II 9.34 (6) (Eu II 9.7 (3)) |
| 3350.48 (1) | 0.44 (1) | | | 0.34 (1) | Gd II 0.47 (10,000) (Gd II 0.10 (400)) (Ni II 0.42 (5)) |
| 3351.65 (1) | 1.76 (1) | | | 1.65 (1) | Fe I 1.74 (80) Fe I 1.52 (70) Eu II 1.56 (40) (Nd III 1.6 (25)) (Ti II 1.67 (5)) |
| 3353.21 (3) | 3.10 (4) | | | 3.06 (4) | Cr II 3.12 (20) Dy II 2.70 (50) Ce III 3.26 (150) (Co II 2.80 (30)) (Nd II 3.59 (20)) |
| 3354.99 (ln) | 4.94 (ln) | | | 4.76 (1) | Pr III 4.9 (600) (Eu II 4.38 (30)) (Eu II 4.51 (10)) (Eu II 4.60 (10)) (Eu II 5.03 (6)) (Gd II 4.92 (25)) (Nd II 4.62 (10)) |
| 3355.29 (1) | | | | 5.27 (1) | Fe I 5.23 (100) (Cr II 5.2 (1)) (Sm III 5.4 (80)) (Eu II 5.42 (20)) |
| 3356.14 (1) | 6.10 (1) | | | 6.22 (2) | Fe II 6.26 (2) Dy II 6.22 (40) Gd II 6.51 (80) (Zr II 6.08 (18)) (Eu II 6.02 (12)) (Nd II 5.92 (40)) |
| 3357.35 (2) | 7.31 (2) | | | 7.37 (2) | Cr II 7.40 (40) Ce II 7.21 (125) Pr III 7.7 (800) (Zr II 7.26 (15)) |
| 3358.48 (3) | 8.40 (3) | | | 8.53 (4) | Cr II 8.50 (75) Fe II 8.25 (3) Gd II 8.62 (8000) (Dy II 8.61 (40)) (Nd III 8.7 (20)) (Co II 8.60 (20)) |
| 3359.52 (1) | 9.37 (1) | | | 9.57 (1) | Pr III 9.5 (700) Dy II 9.48 (40) (Cr II 9.64 (0)) (Sm III 9.3 (40)) (Nd II 9.77 (15)) |
| 3360.24 (2) | 0.25 (3) | | | 0.36 (2) | Cr II 0.29 (100) Fe II 0.10 (3) Gd II 0.71 (1000) Ce II 0.54 (75) (Nd III 0.6 (25)) (Zr II 9.96 (12)) |
| 3361.22 (2) | 1.13 (2) | | | 1.29 (2) | Ti II 1.21 (600) |
| 3361.78 (1) | 1.78 (2) | | | | Cr II 1.77 (30) (Eu II 1.62 (15)) |
| 3362.27 (1) | | | | 2.04 (1) | Gd II 2.23 (10,000) |
| | 2.72 (1) | | | | Gd II 2.94 (125) Tm II 2.62 (300) Fe II 2.76 (0) (Ti II 2.65 (5)) |
| 3363.58 (1) | 3.64 (1) | | | 3.86 (2) | Cr II 3.71 (12) (Gd II 3.97 (30)) |
| 3364.60 (2) | 4.74 (1) | | | 4.47 (2) | Gd II 4.24 (500) (Pr III 4.7 (30)) (Cr II 4.72 (1)) (Eu II 4.21 (15) (Nd II 4.95 (50)) |
| 3366.22 (ln) | 5.87 (1) | | | 5.99 (ln) | Ti II 6.18 (50) Ce II 6.55 (150) Fe II 5.64 (0) Gd II 5.59 (400) Sm II 5.86 (400) (Dy II 5.80 (30)) |

TABLE 2 -- Continued

| Phase | | | | | Identification |
|---|---|---|---|---|---|
| 0.47 | 1.46 | 2.93 | 3.94 | 4.93 | |
| 3367.30 (2) | 7.23 (2) | | | 7.35 (3) | Cr II 7.42 (12) Fe II 6.96 (3) Pr III 7.6 (1,000) Gd II 7.09 (100) Gd II 7.66 (150) |
| 3368.10 (4) | 8.12 (3) | | | 7.96 (4) | Cr II 8.05 (150) Dy II 8.12 (150) (Zr II 7.81 (5)) |
| 3368.94 (2) | 8.93 (2) | | | | Cr II 9.05 (18) Cr II 8.73 (10) Eu II 9.05 (200) |
| 3369.60 (2) | 9.57 (2) | | | 9.44 (3) | Fe II 9.35 (3) Fe I 9.55 (300) Gd II 9.62 (400) Sm II 9.45 (200) |
| 3371.05 (1) | 1.19 (1) | 0.94 (1) | 0.60 (1) | 0.91 (1) | Fe I 0.79 (300) Dy II 0.86 (40) Sm II 1.21 (150) Cr II 0.71 (0) Cr II 1.46 (1) (Co II 0.94 (50)) |
| 3371.98 (2) | 2.14 (3) | 2.10 (1) | 1.87 (1) | 2.07 (2) | Cr II 2.13 (15) Pr III 2.0 (100) Ti II 2.21 (15) Dy II 1.7 (40) Dy II 1.8 (40) |
| 3372.82 (3) | 2.70 (3) | 2.82 (1) | 2.66 (2) | 2.88 (3) | Ti II 2.80 (400) (Cr II 2.45 (0)) (Pr II 2.51 (25)) |
| | | | | 3.63 (1) | Ce II 3.73 (125) Ce II 3.45 (100) (Zr II 3.42 (8)) |
| | | | 3.93 (1) | | Ni II 3.97 (4) |
| 3374.04 (2) | 4.16 (1) | 4.37 (1) | | 4.18 (2) | Ti II 4.35 (30) (Tm II 4.51 (100) (Eu II 4.47 (10)) |
| | 5.04 (2) | 5.03 (2) | 4.94 (2) | 4.85 (1) | Cr II 4.99 (8) Cr II 4.95 (3) Gd II 4.69 (300) (Nd II 5.24 (15)) (Zr II 4.71 (15)) |
| 3375.88 (2) | | | | | (Sm III 5.6 (40)) (Yb II 5.48 (15)) |
| 3376.22 (3) | 6.33 (2n) | 6.40 (2) | 6.49 (1) | 6.34 (2) | Cr II 6.27 (10) (Zr II 6.25 (7)) |
| | | 6.74 (1) | | | Cr II 6.72 (5) |
| 3377.15 (1) | 7.33 (1) | | 7.35 (1) | 7.26 (1) | Cr II 7.36 (5) Ce II 7.13 (300) (Pr III 7.05 (60)) (Zr II 7.45 (6)) |
| 3378.24 (3) | 8.38 (3) | 8.35 (1) | 8.22 (2) | 8.54 (2) | Cr II 8.34 (25) Fe I 8.68 (150) Dy II 8.43 (40) (Zr II 8.30 (5)) |
| 3379.38 (2) | 9.45 (2) | | 9.50 (2) | 9.45 (1) | Cr II 9.37 (30) Ce II 9.17 (100) |
| 3380.07 (3) | 0.15 (2) | 9.83 (2) | 9.90 (2) | 0.24 (4) | Cr II 9.82 (60) Ti II 0.28 (150) Fe I 0.11 (200) Eu II 0.25 (100) Gd II 9.76 (400) Gd II 0.01 (200) Pr III 0.1 (200) |
| 3381.43 (1) | 1.32 (1) | 1.18 (1n) | 1.37 (2) | 1.62 (1) | Fe II 1.00 (4) Pr III 1.2 (300) (Gd II 1.51 (10)) |
| | | 1.93 (1) | | | Pr III 1.7 (200) Eu II 1.73 (30) Gd II 1.79 (40) |
| 3382.69 (3) | 2.69 (4) | 2.71 (2) | 2.63 (2) | 2.74 (2) | Cr II 2.68 (60) |
| 3383.86 (4) | 3.83 (3) | 3.70 (1) | 3.65 (2) | 4.03 (4) | Ti II 3.76 (300) Fe I 3.70 (100) (Gd II 3.68 (20)) |
| | | 4.22 (1) | | | |

TABLE 2 -- Continued

| Phase 0.47 | 1.46 | 2.93 | 3.94 | 4.93 | Identification |
|---|---|---|---|---|---|
| 3384.77 (4) | | | 4.74 (1) | | Sm II 4.66 (300) |
| 3385.08 (2) | 4.98 (1) | 5.15 (1) | 5.22 (1) | 5.36 (2) | Dy II 5.03 (400) (Gd II 5.31 (30)) |
| 3385.87 (1?) | 5.85 (1) | | | | |
| 3386.61 (2) | 6.75 (1) | 6.53 (1) | 6.60 (1) | 6.69 (1) | Fe II 6.45 (1) Fe II 6.72 (2) Dy II 6.58 (60) (Cr II 6.95 (0)) (Nd II 6.52 (20)) |
| 3387.87 (4) | 7.48 (4) | 7.93 (3) | 7.62 (4) | 7.98 (5) | Ti II 7.84 (125) Fe II 8.13 (2) Cr II 7.73 (5) Cr II 7.96 (3) Gd II 8.06 (40) (Nd II 8.02 (5)) (Co II 7.69 (15)) (Co II 8.17 (12)) (Zr II 7.87 (12)) |
| 3388.89 (1) | 8.69 (1) | | | 8.68 (1) | Ti II 8.75 (35) Dy II 8.86 (100) Gd II 8.91 (100) |
| 3389.90 (1) | 9.88 (1) | | | 9.82 (1) | Fe II 0.08 (2) Pr III 0.1 (40) |
| 3391.28 (3) | 1.49 (2) | 1.42 (2) | 1.19 (3) | 1.25 (2) | Cr II 1.43 (35) Fe II 1.30 (1) Gd II 0.88 (200) Pr III 0.9 (100) Gd II 1.29 (150) |
| 3392.10 (1) | 2.04 (1) | | | | Eu II 1.99 (100) Fe I 2.31 (125) Zr II 1.96 (100) Sm III 1.8 (100) (Gd II 2.01 (25)) |
| 3392.89 (2) | 2.88 (2) | 3.07 (3) | 2.65 (2) | 2.85 (2) | Cr II 3.00 (35) Gd II 2.53 (2000) Sm II 2.7 (150) (Eu II 3.26 (15)) (Gd II 3.07 (30)) (Zr II 3.12 (10)) |
| 3393.82 (2) | 3.81 (1) | 3.96 (2) | 3.68 (2) | 3.95 (2) | Cr II 3.86 (30) Gd II 3.63 (400) Dy II 3.58 (400) Ce II 3.92 (50) Eu II 4.06 (20) (Eu II 3.77 (10)) (Nd II 3.64 (60)) (Nd III 4.0 (20)) |
| 3394.32 ($2^+$) | 4.39 (2) | 4.54 (2) | 4.35 (3) | 4.55 ($2^+$) | Cr II 4.32 (35) Ti II 4.57 (200) Fe I 4.59 (150) Pr III 4.2 (100) (Gd II 4.15 (40)) (Pr II 4.61 (75)) |
| 3395.39 (2) | 5.54 (2) | 5.61 (3) | 5.63 (2) | 5.62 (1) | Cr II 5.62 (20) Fe II 5.34 (4) (Ce III 5.73 (50)) (Eu II 5.36 (20)) |
| 3396.64 (2) | 6.68 (1) | | 6.55 (1) | 6.72 (2) | Eu II 6.58 (200) Pr III 6.5 (800) (Cr II 6.50 (0)) (Gd II 6.78 (20)) (Zr II 6.34 (7)) (Zr II 6.66 (6)) |
| 3397.53 (1) | | | 7.44 (1) | 7.73 (1) | Pr III 7.5 (600) Tm II 7.50 (100) (Ni II 7.82 (1)) |
| | 8.12 (1) | | | | Fe II 8.35 (4) (Sm III 8.4 (60)) |
| 3398.71 (2) | 8.90 (2) | | | 8.88 (2) | Ce III 8.91 (20) (Gd II 9.15 (12)) (Ho (II?) 8.98 (S 60)) |
| | | | 9.46 (1nn) | | Cr II 9.54 (18) Fe I 9.34 (200) Gd II 9.41 (500) (Zr II 9.36 (10)) |
| 3399.93 (2) | 9.82 (2) | 9.77 (1) | | 0.01 (2) | Gd II 9.99 (1200) Cr II 0.08 (2) |
| 3401.28 (1) | | 1.21 (1) | | 1.67 (1) | Fe I 1.52 (150) Gd II 1.07 (300) (Ni II 1.76 (2)) |

TABLE 2 -- Continued

| Phase 0.47 | 1.46 | 2.93 | 3.94 | 4.93 | Identification |
|---|---|---|---|---|---|
| 3402.22 (2) | 2.24 (2) | 2.37 (2) | 2.26 (2) | 2.31 (3) | Cr II 2.43 (25) Gd II 2.07 (1000) Ti II 2.42 (90) Sm II 2.46 (500) (Eu II 2.44 (15) |
| 3403.28 (5) | 3.31 (3) | 3.30 (3) | 3.37 (4) | 3.44 (3) | Cr II 3.32 (100) (Gd II 3.08 (150)) (Eu II 3.16 (12)) (Zr II 3.69 (8)) (Gd II 3.34 (40)) |
| 3404.42 (1) | 4.69 (1) | 4.11 (1) | | | Fe I 4.36 (100) |
| 3404.98 (2) | | 5.12 (1) | 4.80 (1) | 4.80 (2) | Gd II 5.04 (150) (Zr II 4.84 (12)) |
| 3405.95 (1) | 5.52 (1) | 5.70 (1) | 5.85 (1) | 5.81 (1) | Ce II 5.98 (100) Cr II 5.3 (1n) (Eu II 5.43 (15)) (Eu II 6.14 (25)) |
| 3406.65 (2) | 6.51 (1) | 6.72 (1) | 6.70 (1) | 7.00 (2) | Fe I 6.80 (100) (Fe II 6.76 (pr)) |
| 3407.45 (2) | 7.27 (2) | 7.40 (1) | 7.45 (1) | 7.66 (2) | Fe I 7.46 (400) Ti II 7.20 (50) Ni II 7.30 (8) Gd II 7.61 (1500) Gd II 7.56 (600) (Dy II 7.17 (40)) |
| | 8.05 (1) | 8.24 (1) | 8.04 (1) | 8.03 (1) | Dy II 7.80 (800) (Dy II 8.16 (60)) (Zr II 8.09 (10)) |

TABLE 3

$\alpha^2$ CVn Region λ 3407 - λ 4740

| 2.363 | Identification |
|---|---|
| 3407.32 (1) | Ti II .20 (50) Ni II .30 (8) (Fe I .46 (400)) |
| 3408.11 (1) | Dy II .80 (800) Zr II .08 (9) (Dy II .16 (60)) |
| 3408.85 (2) | Cr II .76 (150) (Sm II .68 (400)) |
| 3416.05 (0) | Fe II .02 (5) |
| 3416.85 (0) | Ti II .96 (50) Gd II .95 (2500) (Eu II .74 (60)) (Eu II .88 (30)) |
| 3419.47 (0) | Cr II .31 (1) Dy II .64 (50) (Pr II .24 (12)) |
| 3421.16 (3) | Cr II .21 (75) (Eu II .23 (12)) |
| 3421.68 (1) | Cr II .62 (4) (Eu II .67 (25)) |
| 3422.74 (2) | Cr II .74 (125) Ce II .71 (300) Ti II .66 (S 10) Gd II .75 (500) (Fe I .66 (100)) (Dy II .88 (25)) |
| 3423.88 (1n) | Gd II .92 (1500) Co II .83 (20) (Fe I .29 (200)) (Ni I .71 (600)) (Fe II .17 (pr)) |
| 3424.62 (0) | Gd II .59 (1200) Cr II .65 (1) (Zr II .82 (7)) |
| 3425.57 (1) | Fe II .58 (3) (Tm II .63 (150)) (Gd II .62 (50)) |
| 3426.19 (1) | Cr II .13 (8) Gd II .93 (600) Gd II .34 (50) Ce II .21 (250) (Fe I .39 (80)) |

TABLE 3 -- Continued

| 1.323 | 2.363 | Identification |
|---|---|---|
| | 7.18 (1n) | Pr III .0 (300) Ce III .33 (125) Gd II .36 (80) Cr II 7.92 (1) (Cr II .11 (1)) (Fe II 6.81 (pr))(Eu II .04 (6)) (Eu II 8.33 (5)) |
| | 8.45 (0) | Gd II .47 (500) Cr II .94 (7) (Al II .92 (50)) (Eu II .76 (15)) (Nd II .92 (40)) (Eu II .92 (12)) (Eu II 9.25 (15)) (Eu II 9.33 (12)) (Dy II 9.44 (60)) |
| | 0.49 (1) | Cr II .42 (3) Cr II .67 (0) Zr II .53 (30) Gd II .24 (40) (Eu II .37 (15)) |
| | 1.46 (0) | Nd III .4 (30) Gd II .50 (40) (Zr II .57 (6)) |
| | 2.19 (1) | Cr II .32 (2) (Cr II .12 (pr)) |
| | 3.30 (5) | Cr II .31 (75) |
| | 4.15 (2) | Dy II .37 (200) (Zr II .90 (8)) |
| | 5.02 (0) | Eu II .05 (40) |
| | 6.08 (1) | Fe II .11 (5) |
| | 6.60 (0) | Cr II .75 (1) (Pr III .4 (150)) |
| | 7.30 (0) | Pr III .3 (600) (Zr II .16 (10)) (Ni I .28 (600)) |
| | 7.90 (0) | Cr II .93 (2) (Gd II .84 (10)) |
| | 8.22 (1) | Zr II .23 (100) (Cr II .46 (0)) |
| | 8.98 (1) | Mn II .97 (20) Gd II .21 (3000) (Dy II .95 (40)) (Yb II .84 (15)) |
| | 9.76 (1) | Gd II .99 (6000) Gd II .78 (1500) Ce II .83 (60) (Eu II .59 (10)) |
| 3440.71 (1) | 0.58 (1) | Pr III .6 (100) Fe I .61 (500) Sm II .50 (100) Cr II .60 (1) |
| | 1.00 (1) | Fe I .99 (300) Dy II .94 (60) (Eu II .00 (80)) (Eu II .82 (30)) |
| 3441.31 (1) | 1.36 (0) | Ce II .21 (150) Dy II .45 (100) (Tm II .50 (200)) |
| 3441.95 (3) | 1.99 (4) | Mn II .99 (75) (Gd II .79 (400)) (Fe II .90 (0))(Ce II .87 (100)) |
| 3442.50 (0) | | Fe II .24 (3) Ce II .38 (75) |
| | 2.72 (0) | Fe II .79 (pr) |
| | 3.15 (0) | (Nd II .31 (20)) (Ti II .39 (35)) |
| 3443.55 (1) | 3.66 (1) | Ce III .61 (150) (Eu II .54 (6)) (Nd II .60 (15)) (Zr II .57 (7)) |
| 3444.28 (1) | 4.34 (1) | Cr II .34 (4) Ti II .31 (150) |
| 3444.67 (0) | | Fe II .76 (pr) |
| 3445.08 (1) | 5.08 (1) | Cr II .04 (5) Pr III .3 (1000) (Eu II .18 (30)) |
| 3445.67 (0) | 5.55 (0) | Dy II .58 (300) Fe II .58 (pr) |
| 3446.45 (0) | 6.28 (1) | Co II .39 (60) Ni I .26 (1000)(Eu II .37 (20)) |
| | 7.30 (0) | Fe I .28 (100) (Dy II .00 (60)) |
| 3447.86 (0) | 7.72 (1) | (Nd II .62 (8)) |
| | 8.47 (1) | Fe II .43 (1) (Gd II .32 (20)) |
| 3449.39 (1) | 9.21 (1n) | Cr II .28 (2) Gd II .16 (30) Gd II .62 (800) |

TABLE 3 -- Continued

| 1.323 | 2.363 | Identification |
|---|---|---|
| 3450.31 (0) | 0.29 (1) | Gd II .38 (4000) Fe I .33 (150) |
| | 0.89 (0) | Cr II .84 (3) |
| 3451.34 (1) | 1.29 (1n) | Fe II .23 (2) Fe II .32 (2) Gd II .23 (2000) (Fe II .61 (2)) |
| 3452.55 (1) | 2.42 (1) | Ti II .47 (100) (Fe I .28 (150)) |
| 3453.62 (0) | 3.43 (1) | Fe II .60 (2) Eu II .47 (50) |
| | 3.84 (0) | Tm II .66 (200) |
| 3454.12 (0) | 4.25 (2) | Ni II .16 (5) Gd II .14 (1500) Pr III .1 (40) Yb II .07 (60) (Eu II .15 (15)) |
| 3454.45 (0) | | Ce III .37 (150) Dy II .33 (150) (Dy II .52 (40)) (Nd II .39(10)) |
| 3454.91 (2) | 4.99 (2) | Cr II .98 (35) Gd II .90 (2000) |
| 3455.66 (0) | 5.71 (0) | (Ho (II ?) .70 (S 6)) |
| 3456.36 (0) | 6.36 (1) | Ti II .39 (125) (Dy II .57 (80)) |
| 3456.79 (0) | 6.88 (1) | Fe II .93 (5) (Gd II .05 (300)) |
| 3457.58 (1) | 7.60 (2) | Cr II .62 (30) (Zr II .56 (12)) (Eu II .57 (30)) |
| 3458.08 (0) | 8.06 (1) | (Nd II .00 (10)) (Yb (II?) .28 (S 100)) |
| 3458.89 (1) | 8.77 (0) | (Zr II .93 (10)) (Nd II .95 (15)) |
| 3459.38 (2) | 9.29 (3) | Cr II .29 (25) (Ce III .37 (200)) (Eu II .36 (10)) |
| 3459.97 (1) | 0.07 (1) | Mn II .02 (8) Cr II .03 (1) Fe I .92 (80) |
| 3460.28 (2) | 0.37 (4) | Mn II .33 (75) (Eu II .29 (15)) |
| 3460.94 (0) | 0.96 (0) | Dy II .97 (300) Cr II .80 (0) |
| | 1.36 (2) | Cr II .28 (3) (Eu II .38 (80)) |
| 3461.59 (1) | | Ti II .50 (125) (Ni I .65 (800)) |
| 3462.03 (0) | | Gd II .95 (300) Tm II .20 (300) |
| 3462.67 (1) | 2.79 (1) | Cr II .73 (6) |
| 3463.36 (0) | 3.36 (0) | Mn II .33 (6) (Eu II .28 (12)) |
| 3463.96 (1) | 3.99 (2) | Gd II .98 (5000) Mn II .04 (7) Cr II .02 (4) Fe II .97 (1) Gd II .13 (100) (Dy II .88 (20)) |
| 3464.44 (1) | 4.47 (2) | Fe II .50 (3) Sr II .46 (200) |
| 3464.93 (0) | 4.96 (0) | Mn II .04 (8) |
| 3465.53 (1) | 5.44 (0) | Ti II .56 (60) Ni II .62 (1) |
| 3466.10 (1) | | (Fe I .86 (500)) |
| | 6.30 (1) | Mn II .34 (9) Cr II .25 (2) Eu II .41 (40) (Gd II .50 (150)) |
| 3466.98 (1) | 7.08 (1) | Gd II .95 (600) Gd II .27 (3500) Eu II .86 (20) (Fe II .85 (pr)) |
| 3467.74 (0) | 7.92 (0) | Sm II .87 (100) (Gd II .66 (40)) |
| 3468.12 (0) | | Gd II .08 (200) (Ce II .11 (6)) |

TABLE 3 -- Continued

| 1.323 | 2.363 | Identification |
|---|---|---|
| 3468.56 (2) | 8.69 (3) | Fe II .68 (8) (Dy II .44 (60)) |
| 3468.99 (1) | | Gd II .99 (3000) |
| | 9.16 (0) | |
| 3469.47 (0) | | Gd II .31 (100) |
| 3470.17 (0) | 0.14 (1) | Fe II .24 (1) |
| 3470.94 (0) | 0.87 (2) | Ce III .89 (300) Nd II .87 (20) (O II .77 (100)) (P II .82 (S50) (Dy II .15 (50)) |
| | 1.48 (1) | Ni II .35 (2) Dy II .53 (40 + 30) (Fe I .34 (40)) |
| 3471.97 (3) | 2.04 (2) | Cr II .07 (25) |
| 3472.92 (On) | 3.03 (0) | Fe II .89 (0) |
| 3473.28 (0) | | Gd II .22 (2000) |
| | 3.84 (1) | Fe II .82 (2) Dy II .70 (50) (Pr II .85 (30)) |
| 3474.04 (6) | | |
| | 4.17 (3) | Mn II .04 (50) Mn II .12 (40) Dy II .29 (30) |
| 3474.42 (1) | | Pr III .5 (60) Eu II .50 (15) |
| | 4.92 (0) | Sr II .89 (50) (La II .84 (8)) |
| 3475.10 (4) | 5.18 (2) | Cr II .13 (20) |
| 3475.69 (1) | 5.72 (1) | (Fe II .74 (pr)) |
| 3476.12 (0) | 6.26 (0) | Gd II .31 (200) |
| 3476.66 (0) | 6.70 (1) | Fe I .70 (300) (Eu II .60 (30)) |
| 3477.10 (1n) | 7.10 (1) | Ti II .18 (100) Dy II .07 (100) (Eu II .98 (25)) (Ce II .84(150) (Ti II .98 (8)) |
| 3478.00 (0) | 7.84 (0) | Cr II .17 (3) (Gd II .03 (20)) (Gd II .07 (15)) |
| 3478.60 (0) | 8.57 (1) | (Fe II .55 (pr)) (Yb II .84 (80)) (Zr II .50 (3)) |
| 3479.36 (0) | 9.36 (1) | Zr II .39 (30) |
| 3479.86 (1) | 9.85 (1) | Fe II .91 (2) (Cr II .84 (0)) (Cr II .13 (0)) |
| 3480.48 (0) | | Gd II .55 (60) (Zr II .40 (5)) (Eu II .40 (6)) |
| | 1.24 (1n) | Gd II .28 (5000) (Zr II .14 (35)) |
| 3482.00 (0) | | Gd II .80 (3000) (Mn II .06 (1)) |
| 3482.47 (1) | 2.50 (On) | Cr II .58 (12) Fe II .43 (2) Gd II .60 (800) (Eu II .53 (12)) |
| 3482.90 (3) | 2.96 (3) | Mn II .91 (40) (Gd II .95 (10)) |
| 3483.83 (1) | 3.63 (1) | Ti II .80 (70) Gd II .76 (25) Gd II .94 (12) (Zr II .54 (12)) |
| 3484.12 (2) | 4.20 (2) | Cr II .15 (20) (Fe II .35 (1)) |
| 3484.95 (0) | | Ce II .05 (400) |
| | 5.06 (On) | |
| 3485.26 (0) | | Fe I .34 (100) Eu II .16 (15) Eu II .43 (25) (Zr II .31 (5)) |

TABLE 3 -- Continued

| 1.323 | 2.363 | Identification |
|---|---|---|
| 3486.41 (0) | 6.49 (0) | (Ho (II ?) .34 (S 6)) |
| 3486.90 (0) | 6.92 (0) | |
| 3487.58 (0) | 7.41 (0) | Cr II .30 (1) Pr II .57 (25) Dy II .58 (30) |
| 3487.95 (1) | 7.93 (1) | Fe II .99 (3) Fe I .84 (200) |
| 3488.64 (4) | 8.69 (3) | Mn II .68 (40) (Ce II .55 (75)) |
| 3489.08 (1) | 9.22 (1) | Cr II .07 (2) (Pr II .01 (15)) |
| 3489.36 (1) | | Cr II .45 (2) (Gd II .28 (40)) (Eu II .25 (25)) |
| 3489.81 (0) | | Ti II .74 (S 20) (Gd II .76 (30)) |
| 3490.19 (0) | 0.07 (0) | (Er (II?) .06 (S 3)) |
| 3490.58 (2) | 0.60 (1) | Fe I .58 (400) (Eu II .48 (15)) |
| 3491.06 (3) | 1.13 (1) | Ti II .05 (S 8) (Eu II .11 (12)) |
| 3491.40 (0) | | (Gd II .51 (10)) |
| 3491.96 (0) | 1.76 (0) | Gd II .95 (2000) Gd II 1.74 (150) (Pr II .94 (12)) |
| 3492.38 (1) | 2.30 (1) | Ti II .5 (S 35) |
| 3492.72 (0) | 2.80 (0) | |
| 3493.46 (4) | 3.43 (5) | Fe II .47 (10) |
| 3493.81 (0) | | (Tb (II?) .90 (S 3)) (Gd II .03 (80)) (La II .97 (2)) |
| | 4.23 (1) | Pr III .3 (50) Dy II .16 (30) (Gd II .03 (80)) |
| 3494.53 (3) | 4.60 (4) | Fe II .67 (5) Gd II .40 (3000) Dy II .50 (300) (Cr II .52 (4)) |
| 3494.99 (0) | | Eu II .13 (15) |
| 3495.38 (4) | 5.42 (7) | Cr II .38 (25) Cr II .56 (20) (Fe I .29 (100)) |
| 3495.74 (3) | 5.91 (1) | Mn II .83 (40) Fe II .62 (4) (Co I .69 (1000)) (Gd II .94 (20)) |
| 3496.30 (1) | 6.31 (1) | Zr II .18 (50) Dy II .27 (50) (Fe II .34 (0)) |
| 3496.78 (2) | 6.78 (1) | Mn II .81 (20) |
| 3497.12 (0) | 7.25 (0) | Fe I .11 (200) V II .03 (200) |
| 3497.50 (3) | 7.67 (4) | Mn II .54 (25) |
| 3497.87 (4) | | Fe II .81 (2) Fe I .84 (200) Ce III .76 (60) Dy II .84 (40) (Fe II .73 (pr)) (Zr II .90 (12)) (Eu II .84 (10)) |
| 3498.25 (0) | 8.35 (1) | Cr II .35 (1) |
| 3498.77 (0) | 8.88 (0) | Dy II .67 (60) Dy II .94 (30) |
| 3499.47 (0) | | Zr II .58 (8) (Pr II .57 (25)) |
| 3499.86 (2) | 9.78 (1) | Fe II .88 (4) (Cr II .65 (0)) |
| 3500.36 (1) | | Ti II .34 (S 35) (Gd II .18 (30)) (Zr II .15 (4)) |
| 3500.82 (0) | | (Tb (II?) .84 (S 15)) |
| | 1.06 (1) | Cr II .27 (2) |

TABLE 3 -- Continued

| 1.323 | 2.363 | Identification |
|---|---|---|
| 3501.66 (1n) | 1.61 (3) | Ce II .45 (60) Cr II .53 (1) Co II .72 (100) Dy II .44 (40) Gd II .46 (15) Gd II .58 (30) (F II .42 (200)) |
| 3502.20 (0) | 2.16 (1) | |
| | 2.70 (0) | Fe II .78 (0) (Eu II .79 (20)) |
| 3503.34 (1n) | 3.39 (1) | Cr II .36 (3) Fe II .47 (2) (Gd II .21 (60)) |
| 3504.77 (4n) | 4.70 (5n) | Ti II .89 (150) Ce III .60 (100) Dy II .52 (50) Gd II .91 (30) |
| 3505.47 (1) | 5.48 (1) | Gd II .51 (2000) Zr II .47 (15) Dy II .46 (50) (Eu II .30 (20)) (F II .61 (600)) |
| 3505.82 (0) | | Zr II .67 (12) Ti II .90 (S 5) Dy II .83 (20) |
| | 6.12 (0) | (Zr II .04 (4)) |
| 3506.81 (1) | 6.70 (1) | Cr II .61 (1) Dy II .82 (150) |
| 3507.32 (1) | 7.24 (1) | Fe II .39 (3) |
| 3507.81 (0) | 7.78 (1) | Ce II .94 (125) Zr II .66 (4) |
| 3508.23 (0) | 8.24 (1) | Fe II .21 (1) |
| 3509.01 (0) | 9.11 (1) | Eu II .85 (20) |
| 3509.37 (0) | | (Ho (II?) .35 (S 2)) |
| 3509.90 (1) | 9.77 (1) | Ti II .84 (20) |
| | 0.00 (0) | Mn II .97 (0) Gd II .13 (30) (La II .00 (15)) |
| 3510.35 (0) | | Pr III .4 (50) Zr II .46 (7) |
| 3510.87 (3) | 0.77 (2) | Ti II .84 (125) (Nd II .69 (20)) |
| | 1.41 (0) | (Sm II .23 (150) (Zr II .55 (2)) |
| 3511.80 (3) | 1.84 (3) | Cr II .84 (35) (Eu II .86 (10)) |
| 3512.22 (0) | | Gd II .22 (800) (Eu II .27 (5)) |
| | 2.53 (0) | Gd II .50 (600) Dy II .71 (30) (Dy II .56 (20)) (Fe II .72 (2?)) (Zr II .67 (3)) |
| 3513.00 (2) | 3.05 (1) | Cr II .03 (10) (La II .93 (10)) |
| 3513.84 (1) | 3.98 (2) | Ni II .93 (8) Fe I .82 (400) |
| 3514.13 (0) | | Co II .21 (20) Eu II .20 (12) |
| 3514.46 (0) | | Eu II .48 (15) (Zr II .64 (4)) |
| | 4.84 (0) | (Er (II?) .89 (S 5)) (Tb (II?) .04 (S 8)) (La II .87 (2)) |
| 3515.24 (0) | | Cr II .37 (1) (Ni I .05 (1000)) |
| 3515.76 (0) | 5.64 (1) | Fe II .82 (2) |
| | 6.36 (1) | (Fe I .42 (40)) |
| 3517.01 (0) | 6.84 (1) | La III .14 (..) Gd II .78 (60) |
| 3517.38 (0) | 7.40 (2) | Ce II .38 (300) V II .30 (800) Dy II .27 (40) (Co II .45 (10)) |
| | 8.05 (0) | Cr II .01 (1) (Gd II .89 (60)) |

TABLE 3 -- Continued

| 1.323 | 2.363 | Identification |
|---|---|---|
| 3518.56 (1) | 8.55 (0) | Cr II .62 (3) Eu II .48 (25) (Gd II .63 (30)) |
| 3519.20 (0) | | Ce II .08 (25?) |
| | 9.67 (0) | (Fe II .72 (pr)) |
| 3520.24 (2) | 0.14 (1) | Ti II .25 (18) (Eu II .14 (8)) (Yb II .29 (20)) |
| 3521.18 (1) | 0.94 (0) | Eu II .91 (10) Eu II .09 (100) Fe I .26 (300) (Zr II .87 (5)) (La II .72 (10)) |
| 3521.65 (0) | 1.58 (0) | |
| 3522.11 (2) | 2.20 (1) | Cr II .14 (7) Pr III .0 (150) (Nd II .04 (25)) (Fe I .28 (50)) (Ce II .88 (200)) |
| | 2.64 (0) | Pr III .5 (40) (Gd II .45 (50)) |
| | 3.47 (1) | Eu II .49 (30) |
| | 3.82 (0) | (Tb (II?) .66 (S 50)) |
| 3524.03 (0) | 4.13 (0) | Gd II .20 (1000) Dy II .03 (300) (Fe I .07 (50)) (Fe I .24 (60)) |
| | 4.88 (1) | Ti II .87 (5) |
| | 5.52 (0) | (Cr II .28 (1)) (Sm II .50 (S 2)) (Tb (II?) .61 (S 8)) |
| 3526.17 (1) | 6.08 (1n) | Zr II .81 (8) (Fe I .04 (80)) (Fe I .17 (50)) |
| | 6.60 (0) | Eu II .65 (8) Fe I .68 (80) |
| 3526.94 (0) | 6.78 (1) | |
| | 7.33 (0) | Cr II .24 (1) Zr II .42 (7) |
| | 7.92 (1) | Fe I .80 (100) Eu II .87 (30) |
| 3528.85 (0) | 8.82 (1) | |
| | 9.31 (0) | (Eu II .34 (6)) |
| 3529.56 (0) | | |
| | 9.79 (1) | Cr II .73 (2) Fe I .82 (125) (Zr II .99 (5)) |
| 3530.62 (1) | 0.52 (1) | Pr III .5 (60) Sm II .60 (150) Cr II .72 (1) (La II .67 (8)) |
| | 0.87 (0) | V II .77 (100) Zr II .85 (6) (K II .71 (40)) |
| 3531.69 (2) | 1.64 (0) | Dy II .71 (1500) (Eu II .7? (15)) (Nd II .71 (10)) (Cr II .42 (1)) |
| 3532.59 (1) | 2.70 (1) | Fe II .65 (2) |
| 3533.16 (1) | 3.22 (1) | Fe I .20 (50) |
| 3533.63 (0) | | Nd II .59 (30) Pr II .75 (25) (La II .67 (3)) |
| | 3.90 (0) | Ti II .87 (35) Ce II .05 (300) Eu II .12 (20) Cr II .13 (2) |
| | 4.46 (0) | Cr II .37 (1) Gd II .24 (40) |
| 3534.89 (0) | | Dy II .90 (200) Mg II .04 (8) (Gd II .98 (20)) |
| 3535.49 (2) | 5.32 (1) | Ti II .41 (125) Fe II .63 (2) Cr II .50 (1) (Tm II .52 (100)) (Sm II .65 (150)) |
| 3536.06 (1) | | Dy II .02 (400) |

TABLE 3 -- Continued

| 1.323 | 2.363 | Identification |
|---|---|---|
| | 7.25 (On) | Gd II .15 (30) |
| | 8.12 (On) | Cr II .02 (1) Eu II .08 (40) (V II .24 (50)) |
| 3538.99 (1) | 8.98 (1) | Cr II .00 (4) Ce II .09 (300) (Mg II .86 (8)) (Zr II .05 (4)) |
| 3539.55 (0) | | Fe II .55 (3?) Dy II .38 (30) |
| | 0.04 (1) | Pr II .92 (25) (Fe I .12 (100)) |
| 3540.41 (0) | | (Gd II .46 (15)) |
| 3541.05 (1) | 0.92 (0) | Fe I .09 (200) |
| | 2.18 (0) | Fe I .08 (150) Eu II .15 (80) Dy II .33 (100) (Gd II .34 (15)) |
| 3543.30 (0) | 3.26 (On) | Nd II .35 (50) (Gd II .42 (10?)) |
| 3544.10 (1) | 3.98 (1) | Ce III .00 (80) Eu II .85 (60) Eu II .17 (20) Dy II .21 (25) |
| 3545.11 (1) | 4.92 (1) | V II .19 (1000) (Co II .04 (30)) (Gd II .98 (60)) |
| 3545.89 (On) | 5.79 (0) | Gd II .80 (3000) Ce II .19 (150) (Fe I .64 (90)) (A II .84 (125)) |
| 3546.93 (On) | 7.04 (0) | Cr II .10 (3) Dy II .84 (100) (Eu II .10 (20)) |
| | 7.96 (0) | (Dy II .20 (20)) |
| | 9.95 (0) | Yb II .82 (15) (Dy II .23 (300)) |
| | 0.62 (0) | (La II .82 (6)) |
| 3551.87 (0) | | Zr II .94 (18) Dy II .59 (150) |
| | 2.87 (0) | Cr II .7 (2) (Fe I .83 (80)) |
| | 3.64 (0) | Fe I .74 (100) Gd II .72 (40) (Mg II .51 (8)) |
| | *4.99 (1) | Fe I .93 (400) Ce II .99 (150) (Gd II .80 (30)) |
| 3555.35 (0) | | |
| | 5.84 (0) | Co II .94 (6) Nd II .72 (25) |
| 3556.11 (0) | | Cr II .13 (1) |
| | 6.44 (0) | Zr II .61 (30) (P II .48 (100)) |
| 3556.83 (1) | 6.82 (2) | V II .80 (1500) Gd II .05 (1000) (Fe I .88 (300)) |
| 3557.63 (1) | 7.46 (1) | Fe II .55 (2) |
| 3558.15 (0) | 8.28 (1) | Gd II .19 (400) |
| | 8.57 (1) | Fe I .52 (400) Gd II .47 (250) (Sc II .54 (20)) |
| | 9.04 (0) | Sm II .10 (300) (Eu II .09 (6)) |
| 3559.38 (0) | | Ce II .33 (6) (Eu II .42 (3)) |
| 3560.08 (0) | 0.14 (0) | (Yb II .33 (30)) |
| | 0.54 (0) | Cr II .48 (1) V II .59 (90) (Nd II .73 (40)) (Yb II .73 (20)) (Ce II .80 (500)) |
| 3561.01 (1) | 1.01 (2) | Cr II .91 (1) |

* Phase 3.042 begins at wave length 3554.99

TABLE 3 -- Continued

| 1.323 | 3.042 | Identification |
|---|---|---|
| 3561.69 (1) | 1.71 (1) | Ti II .58 (20) Ti II .91 (12) Tb (II?) .74 (200) (Nd II .59 (15)) |
| | 2.77 (0) | |
| 3563.08 (1n) | 2.95 (1) | Dy II .15 (200) |
| 3563.80 (1) | 3.84 (1) | Cr II .92 (5) Dy II .70 (40) Gd II .05 (60) (Eu II .79 (3)) |
| 3564.51 (1) | 4.50 (2) | Cr II .31 (1) Gd II .64 (40) |
| 3565.32 (2) | 5.34 (2) | Cr II .31 (5) Fe I .38 (400) (Ti II .33 (5) (Zr II .41 (5)) |
| 3566.08 (2) | 6.13 (2) | Fe II .15 (3) Fe II .05 (2) (Ti II .99 (S 25)) (Cr II .37 (1)) |
| 3566.91 (1) | 6.93 (1) | Sm II .84 (150) Cr II .75 (1) Gd II .12 (30) Gd II .21 (30) (Fe I .04 (50)) (S II .17 (40)) |
| 3567.63 (0) | 7.65 (0) | Sc II .70 (40) Gd II .65 (40) |
| 3568.87 (0) | 8.82 (0n) | Cr II .70 (1) Nd II .88 (40) |
| | 9.33 (0) | (Cr II .16 (1)) |
| 3569.70 (0) | | Cr II .73 (1) Dy II .67 (20) Gd II .57 (40) |
| 3570.04 (1) | 0.08 (2) | Fe I .10 (300) Eu II .10 (40) (La II .10 (30)) |
| 3570.51 (0) | 0.69 (1) | Gd II .41 (30) |
| 3571.29 (1) | 1.35 (1) | Cr II .37 (3) |
| 3571.99 (1) | 1.88 (1) | Fe I .00 (100) Gd II .93 (300) (Ni I .87 (1000)) |
| 3572.48 (1) | 2.56 (1) | Sc II .52 (50) Zr II .47 (30) (Eu II .58 (20)) |
| 3573.12 (0) | | Zr II .09 (8) |
| | 3.35 (0) | Fe I .40 (50) |
| 3573.80 (1) | 3.69 (1) | Ti II .74 (40) Dy II .84 (60) |
| 3574.56 (0) | 4.49 (1) | (Gd II .74 (150)) |
| 3575.23 (1n) | 5.23 (1) | |
| 3576.23 (1) | 6.18 (1) | Dy II .25 (300) Sc II .34 (45) |
| 3576.79 (0) | 6.78 (0) | Ni II .76 (3) Dy II .87 (150) Zr II .88 (20) Gd II .77 (25) Fe I .76 (80) |
| 3577.20 (0) | 7.25 (1) | |
| 3578.02 (0) | 7.92 (1) | Dy II .99 (60) Co II .03 (30) |
| 3578.63 (2) | 8.68 (1) | Gd II .60 (30) Cr I .69 (500) Eu II .49 (8) (Ti II .69 (5)) (La II .89 (5)) |
| 3579.54 (0) | 9.33 (1) | Gd II .55 (25) (Tb (II?) .20 (S 50)) |
| 3580.09 (0) | | Dy II .04 (40) (La II .10 (8)) |
| | 0.51 (0n) | Gd II .62 (40) |
| 3581.19 (1) | 1.12 (2) | Fe I .20 (1000) |
| 3581.70 (0) | | La II .68 (20) |

TABLE 3 -- Continued

| 1.323 | 3.042 | Identification |
|---|---|---|
| | 1.82 (1n) | |
| 3582.10 (1) | | Gd II .91 (200) Dy II .03 (20) (Zr II .08 (2)) |
| 3582.60 (0) | 2.43 (0) | |
| | 3.05 (0) | |
| 3583.93 (0) | 3.90 (1) | (Cr II .01 (pr)) |
| 3584.60 (1) | 4.50 (1) | Y II .52 (100) Fe I .66 (100) Dy II .43 (40) |
| 3585.34 (10) | 5.42 (9) | Cr II .30 (60) Cr II .51 (40) (Fe I .32 (150)) (Dy II .07 (250)) (Dy II .78 (100)) |
| 3586.13 (1) | 6.09 (1n) | Dy II .12 (50) (Fe I .11 (80)) |
| 3586.60 (0) | | Al II .55 (200) Al II .69 (200) (Gd II .58 (10)) |
| 3587.06 (1) | 7.01 (2) | Ti II .13 (25) Fe I .99 (200) (Al II .06 (100)) (Al II .91 (500)) (Gd II .19 (40)) |
| 3587.76 (0) | 7.84 (0) | Fe I .76 (50) Zr II .98 (7) |
| | 8.88 (0) | (Er (II?) .76 (S 1)) (Er (II?) .95 (S 3)) (Zr II .80 (2)) |
| 3589.50 (0) | 9.48 (1) | V II .74 (1000) (Fe I .46 (50)) |
| 3590.29 (0) | 0.26 (1) | Gd II .47 (100) Eu II .15 (15) |
| 3590.79 (0) | | Cr II .71 (1) Cr II .01 (1) Ce II .60 (125) |
| 3592.02 (0) | 1.89 (0) | V II .01 (800) Gd II .91 (30) Dy II .82 (40) |
| | 2.28 (0) | Dy II .12 (30) (Ho (II?) .22 (S 10)) |
| 3592.66 (0) | | Sm II .60 (1500) Gd II .71 (1500) (Nd II .60 (60)) |
| 3593.34 (2) | 3.42 (1) | Gd II .44 (60) Cr I .49 (500) (V II .32 (600)) |
| | 4.19 (0) | Cr II .33 (1) (Tb (II?) .25 (S 8)) |
| 3594.62 (0) | 4.68 (1) | Fe I .64 (125) |
| | 4.96 (0) | Dy II .05 (125) |
| 3595.21 (0) | 5.40 (0) | |
| 3596.09 (1) | 5.92 (1) | Ti II .06 (60) Dy II .07 (20) (Eu II .15 (10)) |
| 3596.55 (1) | 6.45 (0) | Cr II .34 (1) Cr II .67 (2) (Ti II .55 (S 2)) |
| 3597.05 (0) | 6.97 (0) | Eu II .85 (20) (Fe I .06 (40)) |
| 3597.60 (1) | 7.60 (2) | Cr II .55 (1) (Ni I .70 (1000)) |
| 3598.37 (0n) | 8.40 (0) | (Ce II .20 (50)) |
| 3598.90 (0) | | Cr II .90 (1) (Ho (II?) .77 (S 30)) |
| | 9.69 (0) | Cr II .53 (0) Fe I .62 (40) |
| 3599.93 (0) | | (Ce II .97 (10)) (Er (II?) .83 (S 20)) (Zr II .91 (7)) |
| 3600.32 (1) | | Dy II .34 (50) (Tb II .44 (S 50)) |
| 3600.68 (1) | 0.69 (1) | Ce II .58 (60) Y II .73 (300) (Er (II?) .74 (S 20)) |

TABLE 3 -- Continued

| 1.323 | 3.042 | 4.956 | Identification |
|---|---|---|---|
| | 1.35 (1) | | |
| 3601.60 (1n) | | | Sm II .69 (200) (Al III .62 (6)) |
| | 1.90 (0) | | Y II .92 (60) Gd II .00 (20) |
| | 2.52 (1) | | (Fe II .60 (pr)) (Fe I .53 (50)) (Eu II .49 (12)) |
| 3602.88 (1) | | | |
| 3603.27 (0) | 3.11 (1) | | Eu II .20 (200) Fe I .21 (150) |
| 3603.68 (10) | 3.74 (8) | | Cr II .80 (40) Cr II .86 (20) Cr II .61 (20) |
| 3604.62 (0) | 4.56 (1n) | | |
| 3605.31 (1) | 5.28 (1) | | Gd II .26 (100) Fe I .46 (300) Cr I .33 (500) (Eu II .33 (8)) |
| 3606.00 (0) | 5.96 (1) | | Dy II .13 (150) |
| 3606.64 (0) | 6.64 (1) | 6.72 (1) | Eu II .70 (80) Fe I .68 (200) |
| 3607.00 (0) | | | Gd II .12 (40) (Fe II .05 (pr)) |
| | 7.43 (1) | 7.46 (0) | Cr II .32 (1) (Zr II .39 (7)) |
| 3607.81 (0) | 7.73 (0) | 7.89 (1) | Gd II .90 (20) Ce II .62 (200) |
| | 8.26 (0) | 8.31 (0) | (La II .18 (4)) |
| 3608.62 (1) | 8.72 (2n) | 8.58 (1) | Cr II .66 (3) Eu II .70 (20) |
| 3608.86 (1) | | 8.93 (0) | Fe I .86 (500) Gd II .75 (200) (Tm II .77 (200)) |
| 3609.34 (0) | 9.37 (1) | | Sm II .49 (1200) (La II .22 (4)) |
| 3609.72 (0) | 9.66 (0) | 9.75 (1) | Ce II .69 (250) Nd II .79 (40) |
| 3610.38 (0) | 0.20 (1) | 0.46 (0) | Ni I .46 (1000) La II .25 (30) Fe I .16 (100) (Fe II .33 (pr)) |
| | 0.90 (0) | 1.05 (1) | Gd II .76 (200) Gd II .91 (100) |
| | 1.14 (1) | | Y II .05 (60) Eu II .36 (25) |
| | 1.66 (1) | | Eu II .57 (100) |
| 3611.81 (0) | | 2.00 (1) | Zr II .90 (15) Fe I .07 (80) (Pr II .94 (30)) |
| 3612.34 (1) | 2.30 (1) | 2.48 (1) | Eu II .19 (20) Eu II .46 (8) Zr II .34 (3) (La II .34 (50)) |
| 3613.12 (5) | 3.13 (4) | 3.12 (2) | Cr II .21 (20) Cr II .26 (15) Dy II .06 (15) (Zr II .08 (12)) |
| 3613.64 (0) | | | Ce II .70 (150) Sc II .84 (70) (Mg II .80 (4)) (Gd II .49 (80)) |
| 3614.13 (1n) | 3.95 (0) | 4.10 (1) | Fe II .96 (1?) (Eu II .07 (15)) |
| | 4.23 (1) | | Cr II .26 (2) Gd II .21 (100) (Dy II .08 (20)) (Eu II .26 (8)) |
| 3614.84 (2) | 4.85 (2) | 4.77 (1) | Fe II .87 (5) (Zr II .79 (18)) |

TABLE 3 -- Continued

| 1.323 | 3.042 | 4.956 | Identification |
|---|---|---|---|
| 3615.29 (1) | | 5.22 (1) | Pr II .16 (25) |
| | 5.59 (0) | | (Mg II .64 (2)) (Cr II .45 (pr)) (Tb (II?) .66(S 15)) |
| 3615.81 (1) | | 5.92 (0) | Cr II .79 (1) Nd II .82 (30) |
| 3616.28 (0) | | | Eu II .15 (100) |
| 3616.65 (0) | | 6.51 (1) | Pr II .68 (25) Gd II .46 (12) |
| 3617.25 (1) | 7.24 (1) | | Cr II .32 (7) Gd II .16 (200) |
| 3617.73 (0) | 7.80 (1) | 7.65 (1) | Fe I .79 (125) |
| 3618.27 (0) | 8.26 (1) | 8.28 (1) | Dy II .07 (20) Gd II .06 (15) |
| 3618.65 (1) | 8.73 (2) | 8.84 (1) | Fe I .77 (400) Dy II .52 (40) |
| 3619.19 (0) | 9.30 (0) | | Ni I .39 (2000) Eu II .17 (8) |
| 3619.56 (0) | | | Dy II .47 (15) |
| | | 9.87 (0) | Yb II .81 (15) Cr II .99 (0) (Dy II .96 (20)) |
| 3620.12 (1) | 0.17 (0) | | Dy II .18 (60) |
| | | 0.46 (0) | Gd II .46 (150) |
| 3620.74 (0) | | | Eu II .89 (30) |
| 3621.23 (5) | 1.20 (4) | 1.16 (5) | Fe II .27 (6) (Co II .18 (50)) (Sm II .23 (600)) |
| 3621.60 (0) | 1.68 (0) | | Cr II .51 (1) Fe I .46 (125) (La II .77 (4)) |
| | 2.04 (1) | 1.92 (1) | Fe I .00 (125) Eu II .89 (50) (Ce II .14 (100)) |
| | 2.44 (0) | 2.34 (1) | Cr II .45 (1) Eu II .54 (150) Sm II .50 (100) (Pr II .38 (25)) |
| | | 2.70 (0) | Gd II .81 (60) |
| 3623.09 (0) | 3.24 (0) | 3.32 (1) | Fe I .19 (100) Sm II .32 (200) (Eu II .43 (12)) |
| 3623.80 (0) | | 3.77 (1) | Ce II .84 (200) (Eu II .65 (10)) (Eu II .72 (10)) |
| | 3.96 (On) | 4.12 (1) | Dy II .25 (30) Lu II .98 (40) |
| 3624.87 (3) | 4.87 (3) | 4.87 (5n) | Fe II .89 (5) Fe II .69 (2) Ti II .82 (125) (Gd II .89 (80)) (Nd II .65 (15)) (Cr II .63 (1)) |
| 3625.35 (0) | | 5.34 (1) | Gd II .26 (60) (Fe I .15 (70)) |
| 3625.66 (0) | 5.58 (0) | | (Tb (II?) .54 (S 15)) |
| | 5.96 (0) | 6.04 (0) | (Cr II .92 (pr)) |
| 3626.46 (0) | | | Cr II .31 (1) Gd II .32 (40) Gd II .41 (30) |
| | 7.07 (On) | | Sm II .01 (400) Gd II .90 (15) |
| 3627.36 (0) | | 7.23 (0) | Fe II .17 (1) Eu II .41 (25) |
| | | 8.15 (1) | Ce II .25 (10?) Sm II .97 (100) |
| | | 8.73 (0) | Y II .71 (50) La II .83 (60) |
| | 9.88 (0) | 0.09 (1) | Dy II .18 (250) Eu II .80 (40) Cr II .19 (0) (Zr II .03 (10)) (Nd II .93 (10)) |

TABLE 3 -- Continued

| 1.323 | 3.042 | 4.956 | Identification |
|---|---|---|---|
| 3630.44 (0) | | | Gd II .25 (20) Eu II .50 (12) Dy II .46 (25) |
| | 0.82 (0) | 1.01 (1) | Sc II .74 (70) Ce II .19 (125) Pr II .97 (40) Sm II .13 (400) (Nd II .02 (20)) (Gd II .88 (30)) |
| 3631.53 (5) | 1.54 (6) | 1.66 (2) | Cr II .49 (50) Cr II .69 (40) Fe I .46 (500) |
| 3631.93 (0) | 1.80 (2) | | Eu II .79 (15) Eu II .97 (8) (Fe I .04 (50)) |
| 3632.22 (1) | 2.22 (1) | 2.38 (1) | Fe II .29 (3) Eu II .18 (80) (Ce II .11 (10?)) |
| 3632.67 (0) | | | Dy II .73 (25) |
| 3633.10 (1) | 3.17 (1) | | Y II .12 (100) Dy II .00 (15) |
| | | 3.37 (0) | Zr II .49 (10) (Tb (II?) .29 (S 30)) |
| 3633.97 (1) | 3.94 (On) | 4.14 (1) | Cr II .04 (10) |
| 3634.37 (0) | | | Sm II .29 (1500) Nd II .28 (40) |
| | 4.66 (0) | 4.73 (1) | Gd II .76 (100) |
| 3634.96 (0) | | | Sm II .93 (200) Nd II .87 (15) |
| 3635.37 (1) | | 5.26 (0) | Pr II .28 (30) Dy II .26 (30) Y II .33 (12) |
| | | 5.89 (0) | Eu II .85 (20) |
| | | 6.46 (0) | Zr II .46 (8) |
| | 6.77 (0) | | Eu II .72 (10) Fe II .90 (pr) (Gd II .80 (10)) |
| | | 7.21 (0) | Dy II .27 (25) La II .15 (40) (Nd II .23 (30)) |
| 3638.35 (0) | 8.27 (0) | 8.24 (0) | Fe I .30 (100) |
| 3639.06 (1) | | 8.91 (1) | Gd II .05 (30) Gd II .88 (10) (Sm II .77 (400)) |
| | | 9.36 (0) | (La II .25 (3)) |
| 3639.60 (0) | 9.70 (1) | 9.84 (1) | (A II .85 (25)) |
| | | 0.12 (0) | Gd II .18 (50) Dy II .24 (100) (Nd II .24 (30)) |
| 3640.36 (1) | 0.35 (0) | 0.36 (0) | Fe I .39 (300) |
| 3641.01 (0) | | | Eu II .19 (20) |
| 3641.37 (3) | 1.28 (2n) | 1.28 (2) | Ti II .33 (150) Gd II .39 (125) (Nd II .50 (25)) |
| | | 2.23 (0) | |
| 3642.49 (1) | | | |
| | | 2.74 (0) | Sc II .78 (50) Ti I .68 (300) |
| 3643.17 (2) | 3.20 (2) | 3.34 (1) | Cr II .20 (10) (Pr II .32 (15)) |
| | 3.72 (0) | 3.80 (1) | Dy II .89 (40) Nd II .63 (10) (Ne II .89 (18)) |
| 3644.39 (1) | 4.42 (2n) | 4.24 (1) | (Eu II .46 (12)) |
| 3644.70 (2) | 4.74 (1) | 4.71 (1) | Cr II .69 (10) |
| 3645.38 (1n) | 5.37 (0) | 5.32 (1) | La II .43 (200) Dy II .42 (1000) Sc II .31 (50) Sm II .29 (300) Sm II .39 (200) (Eu II .18 (30)) (Pr II .54 (60)) |

TABLE 3 -- Continued

| 1.323 | 3.042 | 4.460 | 4.956 | Identification |
|---|---|---|---|---|
| | | | 5.80(0) | Dy II .86 (25) Fe I .82 (80) Pr II .66 (75) Gd II .62 (300) (Fe II .78 (pr)) (Nd II .78 (15)) |
| 3646.29(0) | 6.10(0) | | | Gd II .19 (3000) (Pr II .30 (60)) |
| 3646.80(0) | | | 6.90(0) | Ce II .96 (200) Eu II .65 (30) Eu II .75 (35) (Eu II .02 (1z)) |
| 3647.30(2) | 7.36(1) | | 7.46(0) | Cr II .39 (8) |
| 3647.91(2) | 7.87(2) | | 7.87(1) | Fe I .84 (500) |
| 3648.43(1) | | 8.39(1) | | Eu II .26 (15) Pr II .30 (15) |
| 3648.89(1) | 8.70(1) | | 8.74(1) | Ti II .86 (10) Dy II .81 (60) |
| | 9.12(1) | | | Cr II .20 (1) Gd II .00 (10) (Al II .18 (5)) |
| 3649.49(1) | | | 9.39(0) | Sm II .53 (500) Fe I .30 (60) Fe I .51 (100) Gd II .44 (80) |
| | 9.70(1) | 9.80(0) | | (Eu II .81 (5)) (Cr (II?) .66 (2)) |
| 3650.26(2) | 0.38(2) | 0.35(1) | 0.27(1) | Cr II .34 (40) (Nd II .42 (15)) (Sm II .17 (200)) (La II .19 (80)) (Fe I .28 (70)) |
| | 1.05(0) | 0.83(0) | 0.98(0) | Al II .06 (50) Al II .09 (18) Gd II .95 (100) Sm II .00 (150) (Gd II .19 (60)) (Zr II .73 (7)) |
| 3651.60(2) | 1.52(1) | | 1.79(0) | Cr II .66 (12) Fe I .47 (300) (Zr II .50 (2)) |
| 3651.92(0) | | | | Sc II .80 (20) |
| 3652.44(1) | | | 2.50(0) | Gd II .54 (200) Mo II .33 (25) |
| 3652.97(0) | | 3.04(0) | 3.08(1) | Ce II .11 (125) Nd II .15 (15) |
| | 3.46(0) | | | Ti I .50 (500) |
| 3653.73(1) | 3.87(0) | | 3.74(0) | Ce II .67 (250) (Cr II .85 (pr)) |
| 3654.27(0) | | | | |
| 3654.64(0) | 4.66(1) | | 4.60(1) | Gd II .62 (2000) |
| 3655.73(0) | 5.68(0) | | 5.51(0) | Ce II .85 (500) Zr II .56 (7) |
| | | | 6.15(1) | Gd II .15 (1500) Sm II .22 (200) |
| 3656.34(1) | 6.43(0) | 6.40(0) | | Cr II .45 (3) |
| | 6.60(0) | | | |
| 3657.09(0) | | | | |
| | | | 7.35(0) | Eu II .38 (12) |
| 3658.04(1) | 8.07(2) | 8.05(1) | 8.12(1) | Cr II .17 (20) Cr II .94 (1) |
| 3658.66(0) | 8.78(0) | | 8.82(0) | Tb (II?) .88 (S 100) Eu II .77 (10) |
| 3659.26(1) | | | | Ce II .23 (125) Eu II .11 (15) |
| 3659.68(3) | 9.66(1) | 9.57(1n) | 9.64(2) | Ti II .76 (150) Fe I .52 (125) |
| 3660.34(0) | | | | Pr II .38 (30) |

TABLE 3 -- Continued

| 1.323 | 3.042 | 4.460 | 4.956 | Identification |
|---|---|---|---|---|
| 3660.84(1) | 0.56(0) | | 0.73(0) | Ce II .64(250) Eu II .58(15) Eu II .63(12) (Zr II .92(3)) |
| 3661.39(1) | 1.36(1) | 1.32(1) | 1.60(0) | Cr II .44(3) Sm II .36(1000) Gd II .66(30) (V II .38(200)) (Nd II .34(10)) (Pr II .62(25)) (Zr II .33(4)) |
| 3661.92(0) | | | | Dy II .75(15) |
| 3662.22(1) | 2.14(1) | 2.11(1) | 2.18(1) | Ti II .24(100) Gd II .26(800) (Zr II .14(8)) (Eu II .33(20)) (Nd II .26(30)) (La II .08(30)) (Sm II .25(850)) |
| 3662.63(1) | | | | Sm II .69(200) Eu II .50(25) |
| 3663.10(0) | 2.86(1) | | | Cr II .84(8) Eu II .94(30) Sm II .90(200) |
| 3663.72(0) | 3.53(0) | | | |
| 3664.21(1) | 4.00(0) | | | Ne II .11(250) P II .19(100) |
| | 4.46(0) | | | (Er (II?) .44(820)) |
| | 4.68(0) | | 4.62(0) | Gd II .60(2000) Y II .61(100) (Dy II .63(20)) |
| 3664.80(2) | 4.94(2) | 4.95(1) | 5.08(1) | Cr II .94(30) |
| 3665.25(0) | | | | Cr II .29(1) Nd II .18(50) Dy II .20(20) |
| 3665.57(0) | 5.53(1) | | | (Cr II .48 (pr)) |
| 3665.93(1) | 5.98(1) | 5.95(0) | 5.82(0) | Cr II .02(pr) |
| 3666.38(1) | | | 6.46(0) | Eu II .27(15) Ti II .59(1) Sc II .54(8) |
| 3667.02(1) | 6.99(1) | 7.15(0) | 7.16(0) | Fe I .26(80) (Ho (II?) .05(S10)) (Zr II .06(3)) |
| 3668.02(0) | | | | Ce II .98(400) Sm II .93(150) (Fe I .00(60)) (Tm II .09(120)) |
| | | | 8.45(0) | Y II .49(20) Gd II .32(25) (Zr II .48(8)) |
| 3668.68(1) | | | | Ce II .72(12?) |
| | 9.01(0) | | 8.91(0) | Pr II .83(150) S II .05(60) Eu II .14(10) Dy II .91(15) (Ti I .97(100)) (Fe I .16(50)) |
| 3669.49(1) | 9.40(1) | | | Fe I .52(200) V II .41(300) |
| 3670.03(0) | | | | Fe I .07(200) Fe I .03(100) |
| 3670.37(1) | | | | (Ho (II?) .29(S6)) (La II .23(4)) |
| | | | 0.59(0) | Sm II .68(150) |
| 3670.84(0) | | | | Sm II .84(1000) (Eu II .81(12)) |
| 3671.31(1) | 1.08(0) | 1.11(1) | 1.24(1) | Gd II .20(1500) Zr II .28(20) (Gd II .36(30)) |
| 3672.33(1) | | | | Dy II .31(125) Nd II .36(50) (Ce II .17(5d ?)) |
| | | 2.89(1) | 2.90(1) | Ce II .79(60) Dy II .67(40) |
| 3673.12(0) | | | | Eu II .19(80) Dy II .15(40) |
| 3673.72(1) | | | | Nd II .54(50) |
| 3674.18(1) | | | 3.92(0) | Dy II .09(200) |

TABLE 3 -- Continued

| 0.691 | 1.323 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 4.74(0) | 4.79(0) | | 4.64(0) | Zr II .74(40) Eu II .63(50) |
| | | 5.35(0) | | 5.32(0) | |
| | 5.93(0) | | | | (Tb(II?) .78(S8)) |
| | 6.07(1) | | | | (K II .05(10)) |
| | | | | 6.32(1) | Fe I .31(200) (Tb(II?) .35(S200)) |
| | 6.55(1) | 6.50(1) | 6.49(0) | 6.69(0) | Dy II .56(200) Eu II .64(20) |
| | 7.04(1) | | | | (Eu II .87(25)) |
| | 7.33(0) | | | | (Fe I .31(40)) |
| 3677.68(3) | 7.72(x) | 7.79(x) | 7.81(7) | 7.89(3) | Cr II .68(40) Cr II .89(50) (Sm II .79(200)) (Fe I .63(80)) |
| | 8.41(1) | 8.36(0) | | 8.28(1) | Eu II .26(100) (Sc II .34 (15)) |
| 3679.02(0n) | 8.94(0) | 8.72(1n) | 8.72(0) | 8.92(1) | Fe I .86(100) Zr II .91(10) |
| | 9.32(1) | | | | Ce II .42(50) Cr II .34(pr) |
| 3679.57(0) | 9.77(1) | 9.60(0n) | | 9.67(1) | Eu II .50(80) Ti II .69(pr) (F II .67(15)) (Zr II .64(1)) |
| | | 9.97(0) | | 0.10(1) | Fe I .92(500) |
| | 0.25(1) | | | 0.28(0) | |
| 3680.82(1) | 0.79(0) | 0.81(1) | | 0.75(0) | Eu II .76(25) |
| 3681.50(1) | 1.48(0) | 1.30(1) | | 1.28(1) | |
| | | 2.03(0) | 1.95(0) | 2.00(0) | |
| | | | | 2.25(0) | Fe I .21(400) (Tb(II?) .26(S30)) |
| 3682.75(0) | 2.70(1n) | 2.82(0) | | 2.61(1) | Gd II .73(20) (Zr II .67(2)) |
| | 3.44(1) | 3.49(1) | 3.44(1n) | 3.65(1n) | |
| 3684.06(1) | 4.16(3) | 4.23(3) | 4.20(1) | 4.33(2) | Cr II .25(25) Fe I .11(300) |
| | 4.67(0) | | | | (Tb(II?) .81(S8)) |
| 3685.12(5) | 5.16(8) | 5.11(4n) | 5.05(2) | 5.15(4) | Ti II .20(700) (Mn II .05(1)) |
| | 5.80(1) | 5.80(0) | 5.64(0) | 5.85(1) | Nd II .80(60) |
| | 6.21(0) | 6.11(1) | | 6.23(1) | Gd II .33(100) Fe I .00(150) (Mn II .20(1)) |
| | 6.57(2) | 6.65(2) | 6.70(1) | 6.79(1) | Cr II .67(20) |
| | 7.01(1) | | | | Pr II .04(125) Pr II .20(60) |
| 3687.33(0) | | 7.31(0) | | 7.26(1) | Cr II .35(2) Nd II .29(40) |
| | 7.51(0) | 7.49(1) | | | Fe I .46(400) |
| 3687.86(0) | | | | 7.70(1) | Gd II .74(800) Eu II .78(80) (Ce II .80(30 |
| | | | 8.15(0) | 8.33(1) | Sm II .42(100) Mo II .29(15) (Tb(II?) .15(S15)) |
| | 8.56(0) | | | 8.65(0) | Eu II .42(1500) |

TABLE 3 -- Continued

| 0.691 | 1.323 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 9.25(1) | 9.24(0) | 8.98(0) | 9.01(1) | (Tb(II?) .12(S8)) |
| 3689.59(0) | | 9.40(0) | | 9.46(0) | Fe I .46(200) Cr II .62(1) |
| | | 9.83(0) | | 9.72(0) | Nd II .69(30) Pr II .71(20) |
| 3690.06(0) | | | | 0.02(0) | |
| | | 0.23(0) | | 0.33(0) | |
| | 0.74(0) | | | 0.70(1) | Fe I .73(80) |
| | 1.27(0) | 1.01(0) | | 1.14(0) | (Tb(II?) .15(S50) |
| | 1.87(0) | | 1.70(0) | 1.60(0) | H 18 .56(2) |
| 3692.62(1) | 2.46(1) | 2.43(0) | 2.30(1) | 2.38(2) | Sm II .22(150) (Ho(II?) .65(S15)) (Er(II?) .65(S12)) |
| | 3.25(0) | 3.23(1n) | | 3.35(1) | Cr II .12(1) |
| 3693.47(1) | 3.55(0) | | | 3.74(0) | Gd II .60(20) |
| | 4.03(0) | 3.96(1) | 4.04(1) | 4.10(1) | Fe I .01(400) Sm II .99(1200) Gd II .03(80) (Eu II .80(20)) |
| | 4.49(1) | 4.30(0) | | | Yb II .20(1000) Gd II .31(15) Dy II .36(15) (Ne II .20(250)) (La II .27(7)) |
| 3694.87(2) | 5.00(1) | 4.93(1) | 4.77(0) | 4.82(1) | Dy II .75(500) Cr II .97(4) (Nd II .79(10)) |
| | | | | 5.22(1) | (Fe I .05(200)) |
| 3695.86(0) | 5.91(0) | 5.89(0) | | 5.91(1n) | (Cr II .91(1)) |
| | | 6.17(0) | 6.02(0) | 6.22(0) | |
| 3696.42(0) | 6.58(0) | | | | Ti II .39(12) |
| | | 6.75(1) | 6.82(0n) | 6.82(1) | Cr II .78(8) Gd II .76(100) |
| 3697.15(1n) | 7.06(0) | | | 7.18(1) | H 17 .15(3) (Dy II .25(25)) |
| | 7.42(1) | 7.46(1) | | 7.56(1) | Fe I .43(100) Zr II .49(20) (Nd II .54(10)) |
| | 7.92(2) | 8.00(2) | 8.04(2) | | Cr II .00(35) Gd II .73(1000) (Eu II .94(12)) (Pr II .07(25)) |
| | | | | 8.18(2) | Zr II .17(100) Dy II .17(50) |
| | | 8.35(0) | | | |
| | 8.55(0) | | | | (Ce II .65(5?)) |
| | | 9.02(0n) | 9.18(0n) | 9.05(1) | |
| | 9.32(0) | | | | (S II .37(8)) |
| | 9.86(0) | 0.13(0) | | 9.97(0) | Ce II .92(50) (Gd(II?) .75(S250) (Pr II .95(12?)) |
| 3700.36(1) | 0.36(0) | | 0.27(0n) | | V II .34(200) Tm II .26(300) (Nd II .44(10)) |
| 3701.28(1) | 1.28(1) | 1.21(1) | 1.14(1) | 1.27(1) | Fe I .09(300) Tm II .36(250) |

TABLE 3 -- Continued

| 0.691 | 1.323 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 1.81(1) | 2.04(0) | | 2.03(0) | Cr II .90(4) Dy II .62(30) (Pr II .81(20)) (La II .81(40)) (Fe I .03(50)) |
| | 2.74(1) | | 2.80(1) | 2.98(0) | Tb II .85(S200) |
| 3703.38(1n) | | | | | Al II .22(18) Fe I .56(100) (Y II .32(10)) (Eu II .56(25)) (Gd II .51(15)) |
| | 3.81(5n) | 3.72(1n) | 3.71(0n) | 3.75(2n) | H 16 .86(4) (Cr II .70(2)) |
| 3704.07(0) | | | | | |
| | | | | 4.37(0) | Fe I .46(125) |
| 3705.04(0) | 5.02(0) | | 4.86(0) | 4.88(1) | (Cr II .40(pr)) |
| 3705.45(0) | 5.54(1) | 5.48(0) | | 5.42(1) | Fe I .57(700) |
| 3705.80(0) | 5.90(1) | | | | La II .81(80) |
| 3706.14(5) | 6.23(3) | 6.07(1) | 6.05(1) | 5.96(3) | Ti II .23(125) Ca II .03(40) (P II .05(150)) |
| 3706.84(1n) | 6.98(1) | 7.03(0) | 7.09(0n) | 6.85(0) | Cr II .13(3) Cr II .69(1) Sm II .75(300) Fe I .05(150) Sm II .17(100) Sm II .98(200) (Mn II .91(1)) (Pr II .77(50)) |
| 3707.51(0n) | 7.57(0) | | | 7.38(1) | Eu II .42(20) Dy II .42(30) Dy II .57(40) (Gd II .59(10)) (Gd II .71(8)) |
| | 8.15(0) | 8.01(0) | | 8.11(1) | Mn II .06(1) Fe I .92(80) (Dy II .23(40)) |
| 3708.88(0) | | 8.61(0) | | 8.61(0) | Sm II .65(300) |
| 3709.25(1) | 9.25(2) | 9.20(2) | 9.21(3) | 9.29(3) | Fe I .25(600) Ce II .29(400) Zr II .27(60) (Gd II .13(50)) |
| 3709.86(0) | 9.93(1) | 9.83(0) | 0.04(0) | 9.99(1) | Ce II .93(500) Cr II .09(1) Dy II .08(30) (Mn II .88(1)) |
| 3710.38(1) | | 0.27(1n) | | | Y II .29(150) Eu II .28(10) (Zr II .47(1)) |
| | | | | 0.62(0) | Sm II .87(100) Eu II .87(80) |
| 3711.18(1n) | | | | 1.06(1n)* | Cr II .28(7) Fe I .22(80) (Pr II .10(25)) (Na II .07(60)) |
| | | | 1.57(0) | 1.68(1) | Sm II .54(200) Dy II .65(20) |
| 3711.94(2n) | 1.78(8n) | 1.75(2n) | | 1.81(3n) | H 15 .97(5) |
| | | | | 2.21(1) | Sm II .11(100) Fe II .97(1) |
| | | | 2.52(0) | 2.63(1) | Gd II .70(2000) Sm II .76(200) |
| 3712.82(2) | 2.87(x) | 2.93(6) | 2.95(2) | 2.99(2) | Cr II .95(50) |
| | 3.39(1) | | 3.62(0) | 3.50(1) | Eu II .45(125) La II .54(100) Nd II .70(25) |
| 3713.89(0) | 3.87(1) | | | | Dy II .84(15) |
| | 4.33(0) | 4.07(0n) | | 4.16(0) | Nd II .19(15) |
| | | 4.49(0) | | | |

TABLE 3 -- Continued

| 0.691 | 1.323 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3714.71(0) | | 4.78(0) | 4.77(1) | 4.82(1) | Eu II .90(100) Zr II .77(15) (Nd II .73(12)) (Nd II .81(20)) (Nd II .05(15)) (La II .87(40)) |
| 3715.06(3n) | 5.34(6) | 5.25(6n) | 5.38(3) | 5.43(3n) | Cr II .19(20) Dy II .28(15) (Gd II .23(8)) |
| | 5.45(4) | 5.50(2) | | | Cr II .43(20) V II .48(1200) (La II .53(50)) (Nd II .39(15)) |
| | 5.78(1) | 6.20(1) | 6.25(1) | | Fe I .92(80) P II .85(50) (Nd II .68(20)) |
| 3716.36(1n) | 6.46(1) | | | 6.36(1n) | Ce II .36(600) Gd II .36(1000) (Fe I .45(150)) (Nd II .58(10)) |
| 3716.98(1) | 7.11(0) | 7.02(0n) | 6.94(0) | 6.98(1) | Eu II .94(60) Dy II .93(15) (Ce II .93(10?)) (Zr II .02(2)) |
| | 7.55(0) | | 7.62(0) | 7.59(0) | Eu II .69(80) Mn II .53(1) (P II .62(70)) (Gd(II?) .49(850)) |
| 3718.28(0) | | | | 8.23(0) | Ce II .19(150) (A II .21(15)) |
| | | | 8.44(0) | | Fe I .41(80) Ce II .38(200) |
| 3718.73(0) | | | | | Sm II .88(500) (Zr II .86(6)) |
| 3719.48(1) | | 9.55(0) | 9.39(1) | 9.37(1) | Gd II .45(800) Gd II .53(300) |
| 3719.83(0) | | 9.92(2) | 9.94(1) | 0.04(1) | Fe I .94(1000) (Ce II .80(15?)) (Cr II .72(1)) |
| | | 0.58(0) | 0.45(0) | 0.73(1) | Eu II .72(10) Eu II .39(8) |
| 3721.77(9n) | 1.71(9n) | 1.82(4n) | 1.63(1n) | 1.83(9n) | H 14 .94(6) Ti II .64(125) (Sm II .85(400)) (Cr II .14(1)) (Gd II .07(100)) |
| | 2.46(0) | | | 2.52(0) | Fe I .56(500) |
| | 3.28(0) | 3.41(1) | 3.40(1) | 3.48(0) | Cr II .40(15) (Ti II .63(15)) (Nd II .51(50)) (Gd II .24(8)) (Gd II .69(20)) |
| 3724.08(0) | | 4.22(0) | 4.22(1n) | 4.19(1) | Ti II .11(18) Fe I .38(200) (Dy II .42(125)) |
| 3724.96(2) | 5.02(1) | 4.70(1) | 4.75(1) | 4.83(2) | Eu II .94(4000) (Mn II .81(1)) (Nd II .88(30)) (La II .05(20) (Sm II .90(200)) |
| 3725.23(0) | | 5.22(1) | 5.33(1) | 5.38(0) | Fe II .30(3) (Mn II .29(1)) |
| 3725.82(1n) | 5.87(1) | 5.83(1n) | 5.81(1) | 5.69(2n) | Fe II .90(2) Gd II .47(200) (Ce II .68(40?)) |
| 3726.33(0) | | 6.40(0) | | 6.54(1) | (Pr II .31(15)) |
| 3726.92(1) | 6.96(2) | 6.96(2) | 6.94(2) | 7.05(4) | Fe II .04(4) Fe I .92(100) (Sm II .80(100)) (Ne I1 .08(125)) |
| 3727.23(2) | 7.32(3) | 7.44(2) | 7.44(1) | 7.48(2) | Cr II .36(40) V II .35(1000) (O II .30(50)) |
| | 7.69(1) | | | 7.77(1) | Fe I .62(200) Zr II .72(10) |
| | 8.02(1) | | | | Nd II .13(50) |
| 3728.22(0n) | 8.43(0) | 8.41(0) | | 8.32(0) | Ce II .42(250) Sm II .47(400) (V II .34(200)) |
| 3728.71(0) | 8.89(0) | | | 8.58(1) | (P II .66(50)) |

TABLE 3 -- Continued

| 0.691 | 1.323 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| | | | | 9.03(0) | Eu II .06(15) |
| 3729.52(0) | 9.43(1) | 9.43(0) | | 9.45(2) | Mn II .49(1) Pr II .40(15) |
| | 9.78(1) | | | | Eu II .68(30) Eu II .74(20) (Ti I .82(500)) (Zr II .74(5)) |
| 3730.09(0) | 0.10(1) | | | 9.96(1) | (Tb(II?) .91(815)) |
| | 0.47(0) | | 0.70(0) | 0.64(0n) | Nd II .58(30) Pr II .58(30) Fe I .39(70) |
| 3730.84(0) | | | | | Gd II .84(1000) (Fe I .95(50)) |
| | 1.33(1) | | 1.07(0) | 1.18(0) | Zr II .26(35) Sm II .26(600) Nd II .22(20) (La II .42(8)) |
| | | | | 1.67(1) | Cr II .64(1) |
| | 1.93(0) | | | | Eu II .84(25) (Al II .95(2)) |
| | | | 2.52(0) | 2.52(0) | Fe I .40(200) Gd II .45(100) |
| | 3.18(1) | | | 2.98(1) | Gd II .08(300) Pr II .03(60) (Nd II .76(10)) |
| | | | 3.31(0) | 3.44(1) | Fe I .32(400) Eu II .65(25) |
| 3734.34(xn) | 4.47(xn) | 4.25(9n) | 4.37(3n) | 4.42(xn) | H 13 .37(8) |
| | | | | 4.86(0) | Fe I .87(1000) (Eu II .85(15)) |
| | | | 5.78(0) | 5.92(1) | Sm II .98(500) Cr II .90(2) Eu II .94(20) Eu II .06(10) (Pr II .76(40)) (La II .85(10)) |
| 3736.44(0) | | | 6.66(0) | | Cr II .56(1) (Pr II .50(40)) (La II .41(15)) |
| 3737.02(2) | 7.06(1) | 6.88(1) | 7.11(1) | 6.84(1) | Fe I .13(1000) Ca II .90(50) (Sm II .14(200)) (Gd II .26(10)) |
| | | | | 7.26(0) | |
| 3737.51(1n) | 7.48(1) | 7.59(1) | 7.48(1) | 7.64(1) | Cr II .55(10) |
| | 7.91(0) | | 7.96(1) | 8.00(0) | Eu II .08(80) Nd II .06(40) (A II .89(15)) (Al II .00(10)) |
| 3738.21(2) | 8.28(7) | 8.33(6) | 8.38(2) | 8.46(1) | Cr II .38(25) (Fe I .31(100)) (Zr II .13(5)) |
| 3738.83(0) | 8.87(1) | 9.04(0) | | 8.90(0) | |
| | 9.20(1) | 9.32(0n) | 9.24(0) | 9.28(1) | Sm II .12(300) Dy II .36(25) Sm II .20(200) (Pr II .19(100)) |
| 3739.50(2) | 9.66(1) | | | | (Fe I .53(80)) |
| 3740.08(1) | 0.17(1) | 9.83(0) | 0.09(0) | 0.14(1) | Gd II .02(150) (O II .92(35)) |
| 3740.27(0) | | | | | Fe I .25(70) Eu II .25(20) |
| 3740.86(0n) | 0.69(0) | 0.82(0) | | 0.93(1) | |
| 3741.51(6) | 1.58(9) | 1.54(4) | 1.56(3) | 1.64(5) | Ti II .64(200) Eu II .31(400) (Eu II .62(12)) (Nd II .43(50)) |
| | 2.18(0) | | 2.27(0) | 2.25(0) | Eu II .34(15) (Cr II .20(pr)) |

TABLE 3 -- Continued

| 0.691 | 1.323 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3742.40(0) | 2.54(1) | | | 2.58(1) | (Fe I .62(50)) |
| | 3.05(1) | | | 2.89(0) | Cr II .97(1) |
| 3743.40(9) | 3.41(3) | 3.33(5) | 3.28(3) | 3.35(9) | Gd II .47(2000) (Fe I .36(200)) (Eu II .56(100)) |
| 3743.92(0) | 3.98(0) | 4.01(1) | 3.96(1) | 4.03(1) | Sm II .87(500) Pr II .99(20) |
| 3744.34(0) | | | | 4.54(1) | Eu II .54(20) |
| | 4.78(0) | 4.96(0) | 4.84(1) | 4.91(1) | (Gd(II?) .80(S12)) |
| 3745.12(0) | 5.30(1) | | | | (Fe II .36(pr)) |
| 3745.50(1) | 5.58(0) | 5.43(1) | 5.49(0n) | | Fe I .56(500) Nd II .60(200) |
| 3745.83(3) | 5.89(3) | 5.75(3n) | 5.76(1) | 5.73(7n) | V II .81(800) Fe I .90(150) (Zr II .97(40)) |
| 3746.49(1) | 6.55(1) | 6.55(1) | 6.39(1) | 6.62(1) | (Fe II .56(pr)) (Gd II .44(8)) |
| 3746.99(0) | 6.97(1) | | | | (Fe I .93(40)) |
| 3747.54(0) | 7.62(0) | 7.48(0) | | 7.51(0) | Fe II .50(2) |
| | | 7.98(0) | | 8.03(1) | Fe I .26(500) Ti II .00(25) (Ce II .06(150)) (Dy II .1(20)) (Dy II .83(100)) |
| | | 8.63(2) | 8.65(1) | 8.59(1) | Fe II .49(8) Cr II .68(7) (Gd II .88(50)) |
| | | 9.44(1) | | | Fe I .49(1000) |
| 3750.08(xn) | 0.13(xn) | 0.09(xn) | 0.02(3n) | 0.14(xn) | H 12 .15(10) |
| | | | 1.44(0) | 1.50(0) | Cr II .60(3) Cr II .43(1) (Zr II .60(75)) |
| | | | | 2.49 ) | Nd II .50(40) Nd II .68(30) (Eu II .51(5)) (Gd II .66(8)) |
| | 2.88(0) | | 2.92(0) | | Eu II .05(30) Eu II .83(15) (Ti I .86(200)) (Nd II .68(30)) |
| 3753.70(2) | 3.60(1) | 3.55(1) | 3.69(0) | 3.59(1n) | Dy II .76(200) Dy II .51(150) (Fe I .61(150)) (Gd II .56(10)) |
| | 4.00(1) | 4.05(0) | | 4.19(0) | |
| | | 4.38(0) | | | |
| 3754.42(1) | 4.53(2) | 4.59(6) | 4.59(3) | 4.67(4) | Cr II .58(20) |
| 3754.83(1) | | | | | (Sm II .86(S10)) |
| | 5.07(1) | 5.16(1) | 5.15(1) | 5.19(1) | Cr II .13(2) Sm II .28(200) (Gd II .24(30)) (Tb(II?) .24(100)) |
| 3755.46(2) | 5.61(2) | 5.60(2) | 5.60(1) | 5.63(1) | Fe II .56(4) Ce II .42(75) (Gd II .56(40)) (Nd II .60(30)) |
| | 6.15(0) | 6.31(0) | 6.08(0) | 6.28(1) | (Gd II .09(10)) |
| 3756.50(1n) | 6.50(1) | 6.57(1) | 6.50(1) | 6.63(0) | Cr II .55(3) Sm II .41(600) |
| | 7.07(1) | 7.05(0) | | 6.88(0) | Fe I .94(80) (Zr II .96(1)) |

TABLE 3 -- Continued

| 0.691 | 1.323 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3757.40(0) | 7.44(1) | | 7.18(1) | 7.27(2) | Dy II .37(500) Eu II .42(15) |
| 3757.69(3n) | 7.72(2) | 7.66(1) | 7.66(2) | 7.72(3) | Ti II .69(100) Sm II .53(300) Gd II .74(80) (Eu II .64(30)) (Ce II .86(15?)) (Nd II .82(30)) (Zr II .80(8)) |
| 3758.16(2) | *8.22(2) | 8.19(4) | 8.23(3) | 8.29(4) | Fe I .24(700) Gd II .31(200) (Eu II .29(30)) |
| 3758.43(1) | 8.67(1) | | | | Cr II .46(1) Eu II .54(20) |
| | | 8.79(0) | 8.80(1) | 8.94(1) | Gd II .00(300) La II .08(300) Sm II .97(200) (Nd II .94(40)) |
| 3759.27(9n) | 9.36(8) | 9.36(9) | 9.38(5) | 9.36(9n) | Ti II .30(400) Fe II .46(6) |
| 3759.80(0) | 9.85(1) | 0.06(9) | 0.01(0) | | Cr II .94(1) Pr II .61(75) (Nd II .80(20)) |
| 3760.15(1) | 0.21(1) | | | 0.04(1) | Fe I .05(150) Eu II .33(50) (Pr II .08(30)) |
| †3760.80(1) | 0.64(1n) | 0.58(0) | 0.58(1) | 0.66(1) | Sm II .69(500) Fe I .53(100) Gd II .71(200) Gd II .92(100) (Ce II .69(6)) |
| 3761.26(3) | 1.27(6) | 1.24(3n) | 1.26(3) | 1.24(5) | Ti II .32(300) Eu II .12(300) (Tm II .33(800)) |
| 3761.52(0) | | | | | |
| 3761.77(2) | 1.80(6) | 1.80(5) | 1.81(4) | 1.89(5) | Cr II .70(7) Cr II .87(8) Ti II .89(15) (Pr II .87(250)) (P II .81(30)) (Tm II .91(600)) |
| 3762.05(0) | | | | | Tm II .91(600) |
| | 2.39(0) | 2.36(0) | 2.41(1) | 2.28(0) | |
| | | | | 2.69(0) | Sm II .59(200) |
| 3762.87(2n) | 2.90(2n) | 2.88(3) | 2.91(2) | 2.99(2) | Fe II .89(5) (Gd II .00(50)) |
| 3763.33(0) | | | | | Nd II .48(60) Gd II .33(60) |
| 3763.70(2) | 3.79(3) | 3.74(3) | 3.74(1) | 3.65(1) | Fe I .79(500) |
| 3764.19(0) | 4.19(1) | 4.09(1) | 4.10(2) | 4.16(3) | Ce II .12(150) Fe II .09(?) (Gd II .15(15)) (Gd II .20(50)) |
| | | | 4.41(1) | | Sm II .37(300) |
| 3764.85(1) | | 4.79(0) | 4.92(0) | 4.65(0) | Pr II .81(125) Gd II .60(50) |
| 3765.15(0) | 5.18(0) | 5.12(0) | | 5.04(1n) | Cr II .28(3) Cr II .32(1) (Tb (II?) .14(S100)) (Ce II .04(12?)) |
| 3765.45(2) | 5.57(3) | 5.58(3) | 5.58(2) | 5.67(1) | Cr II .61(8) Fe I .54(200) |
| 3766.20(0) | | | 5.97(0) | 6.09(0) | Eu II .93(150) |
| 3766.39(0) | | 6.31(1) | | | (Ne II .29(75)) |
| 3766.49(1) | 6.63(2) | 6.58(2n) | 6.61(1n) | 6.51(1) | Cr II .65(4) Zr II .83(25) (Ce II .51(?4n)) (La II .58(3)) |

* Phase 1.482 begins at wave length 3758.22

† Phase 0.756 begins at wave length 3760.80

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3767.14(1) | 7.21(2) | 7.18(2) | 7.08(1) | 7.26(1) | Fe I .19(500) Gd II .04(500) Sm II .36(200)) (La II .05(5)) |
| 3767.95(0) | | 7.77(0) | | 7.78(0) | Sm II .76(150) (Zr II .89(5)) |
| 3768.52(1) | | 8.33(1) | 8.29(1) | 8.36(2) | Gd II .38(2000)(Gd II .50(60)) |
| | | 9.66(0) | | | Nd II .64(40) Gd II .45(100) (Pr II .70(30)) (Ni II .46(5)) |
| 3770.53(x) | 0.36(xn) | 0.52(xn) | 0.55(6n) | 0.62(xn) 1.58(0) | H 11 .63(15) (Gd II .69(300)) |
| 3772.02(0) | | | | | Cr II .00(1) Cr II .10(1) Nd II .06(15) (Zr II .06(4)) (Zr II .98(2)) |
| | | | 2.45(0) | 2.46(0) | |
| | | | | 2.89(0) | Pr II .85(100) |
| | | 3.06(0) | | 3.19(0) | La II .12(150) |
| 3773.56(0) | 3.54(0) | 3.44(0) | | 3.62(0) | Dy II .32(25) Fe I .70(40) |
| 3774.35(1n) | 4.22(2) | 4.25(1) | 4.03(0) | 4.22(1) | Y II .33(100) Pr II .06(75) (Sm II .29(150)) (Gd II .30(80)) |
| 3774.91(0) | | | | 4.75(1) | Fe I .83(100) (Ti II .65(1)) |
| 3775.26(0) | | | 5.31(0) | 5.13(0) | Cr II .09(1) Eu II .47(4) (P II .02(30)) |
| | 5.81(0) | 5.87(0) | | 5.56(1) | Cr II .73(0) Nd II .50(20) (Ni I .57(500)) (Eu II .69(5)) |
| 3775.97(2) | 6.22(1) | 6.14(1) | 5.99(1) | 6.02(1) | Ti II .06(60) Fe I .46(125) |
| 3776.66(0) | 6.69(1) | 6.58(0) | 6.52(0) | 6.70(0) | (Y II .56(12)) (Eu II .51(5)) (Tb(II?) .49(S100)) |
| | 7.36(0) | | | 7.19(1) | (Ne II .16(75)) (Er(II?) .09(S10)) |
| 3777.64(1) | 7.70(1) | 7.49(1) | 7.43(1) | 7.46(1) | Pr II .63(50) Eu II .61(15) |
| 3778.23(1) | 8.21(1) | 8.24(1) | 8.23(0) | 8.02(0) | Sm II .14(400) |
| 3778.54(1) | 8.62(1n) | 8.60(2n) | 8.69(1) | 8.40(0) | Cr II .69(6) Fe I .51(60) (Fe II .37(pr)) |
| | | | | 8.80(0) | (Eu II .87(6)) (Eu II .65(4)) |
| | | | | 9.16(0) | Cr II .06(1) Cr II .12(0) (Dy II .25(25)) |
| 3779.48(2) | 9.58(2) | 9.52(1n) | 9.50(2) | 9.67(2) | Fe I .45(100) Nd II .47(40) |
| 3779.84(0) | | 0.14(0) | | 9.97(0) | Gd II .83(20) (Eu II .87(6)) |
| 3780.56(0) | | 0.49(1n) | 0.62(1n) | 0.41(1) | Cr II .49(2) Eu II .54(10) Nd II .39(20) (La II .53(50)) |
| 3780.88(1) | | 0.74(1) | | 0.90(1) | Sm II .93(150) Sm II .76(200) Pr II .66(50) (Fe I .19(40)) (La II .67(50)) (A II .84(8)) |
| 3781.45(2) | 1.49(2) | 1.48(2) | 1.44(1) | 1.53(2) | Fe II .51(1) Eu II .40(50) (Ce II .62(150)) (Nd II .32(20)) |
| 3781.93(0) | 1.95(0) | 2.04(1) | | | |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| | | 2.28(1) | 2.22(1) | 2.21(2) | Gd II .34(300) Cr II .18(2) Cr II .34(1) (Zr II .24(4)) |
| 3782.38(2n) | 2.46(1) | | | 2.54(1) | Ce II .52(75) |
| 3782.82(1) | | | 2.98(1) | 3.06(0) | Dy II .89(20) (Zr II .72(5)) |
| 3783.25(2) | 3.30(3) | 3.30(3) | 3.40(2) | 3.43(2) | Fe II .35(4) Cr II .56(2) (Ni I .53(500)) (S II .16(8)) (Tm II .56(60)) |
| 3783.70(1) | 3.73(1) | | | 3.84(1) | Gd II .73(20) Cr II .81(1) |
| 3784.04(0) | | | | | |
| 3784.25(1) | 4.40(1) | 4.17(1) | 4.14(1) | 4.39(1) | Nd II .25(80) Eu II .26(15) |
| 3784.68(0) | 4.75(0) | 4.67(0) | 4.90(0) | 4.96(1) | Nd II .85(20) La II .81(15) |
| 3785.12(0) | | | | | Cr II .23(1) |
| 3785.46(1n) | 5.45(1) | | | 5.41(1) | Cr II .35(1) Dy II .42(30) (Pr II .50(50)) (Eu II .48(4)) |
| | 6.07(0) | | 5.84(0) | 6.06(2) | Fe I .95(125) Eu II .82(15) |
| 3786.22(3) | 6.40(2) | 6.23(1n) | | 6.37(1) | Dy II .20(300) Fe I .18(100) |
| 3786.61(0) | 6.66(1) | | 6.64(1) | 6.73(1) | Ce II .63(150) Fe I .68(125) (P II .69(15)) |
| 3787.00(0) | 7.02(1) | | | | Pr II .88(75) Eu II .98(8) |
| 3787.37(0) | 7.41(1) | 7.20(0) | | 7.11(1) | Sm II .20(100) V II .24(150) |
| | | | | 7.57(0) | Gd II .56(400) |
| 3787.79(1n) | 7.77(2) | 7.84(1) | 7.86(0) | 7.85(1) | Fe I .88(500) |
| 3788.39(3n) | 8.51(2) | 8.43(1n) | 8.30(1) | 8.36(3) | Dy II .45(150) (Sm II .12(400)) |
| 3788.61(1n) | 8.78(1) | 8.64(0) | 8.77(0) | 8.82(0) | Ce II .75(75) Eu II .76(30) (Y II .70(30)) |
| 3789.23(0) | 9.31(0n) | | | 9.22(1) | Fe I .18(80) Eu II .17(10) |
| | 9.52(0) | 9.65(0) | | | |
| 3789.97(1) | 0.15(1) | | | 9.83(1) | Fe I .10(200) (Cr II .89(pr)) |
| 3790.47(1) | 0.65(0) | | 0.24(0) | 0.35(1) | Gd II .44(20) |
| 3791.17(1) | 1.20(1) | | 1.05(0n) | 1.10(1) | Gd II .17(300) |
| 3791.89(1) | 1.82(0) | 1.70(1n) | 1.71(1) | 1.73(3) | Cr II .75(2) Dy II .82(50) Sm II .02(150) Eu II .50(30) Gd II .72(30) |
| 3792.47(1) | 2.43(1) | 2.33(1n) | 2.39(0) | 2.34(1) | Gd II .39(200) Ce II .33(50) Pr II .52(100) (S II .46(35)) (Zr II .32(2)) |
| 3793.06(0) | | | | 3.09(0) | Eu II .06(25) |
| 3793.50(0) | | | | | (P II .60(30)) (Tb(II?) .55(S15)) |
| 3794.19(0) | | | | | Sm II .97(500) Fe I .34(80) |
| 3794.71(0) | | 4.62(0) | | 4.63(1) | La II .77(400) |
| | | | | 6.43(0) | Gd II .37(2500) Zr II .47(20) (Eu II .33(8)) |
| | | | | 7.06(0) | Ti II .88(15) Sm II .28(150) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3797.86(x) | 7.80(xn) | 7.94(xn) | 7.79(8n) | 7.87(xn) | H 10 .90(20) (Sm II .73(600)) (Cr II .95(1)) |
| | | 8.89(0) | | | Eu II .01(100) |
| | 9.53(0) | 9.46(0) | | 9.67(0) | Fe I .55(400) Sm II .54(300) Cr II .62(1)(Eu II .49(10)) |
| | | 0.34(0) | 0.26(0) | | Mn II .24(2) Pr II .30(200) Sm II .37(100) |
| | | | | 0.66(0) | Sm II .89(400) Gd II .68(15) (Eu II .55(10)) (Zr II .73(5)) |
| 3801.06(0) | 1.15(0) | 1.21(1) | | 1.32(0) | Cr II .21(10) Gd II .29(400) |
| 3801.40(1) | 1.58(1) | 1.77(0) | | | Ce II .53(500) Mn II .63(3) (Eu II .58(8)) (Fe I .68(50)) |
| 3801.99(0) | 1.99(0) | | | | |
| | | | | 2.48(0) | |
| | | | 2.89(0) | 2.82(0) | Gd II .85(40) Mn II .96(0) |
| 3803.42(0) | 3.50(0) | 3.21(0) | | 3.25(0) | Ce II .10(200) Nd II .47(40) |
| 3804.08(1) | 4.09(0) | 3.88(0) | 4.00(1n) | 3.98(1) | Cr II .10(1) Dy II .15(40) (Mn II .88(0)) (Fe I .01(40)) |
| 3804.72(1) | 4.85(0) | | | 4.77(1n) | Pr II .85(75n) |
| 3805.24(1) | 5.36(1) | 5.28(1) | 5.38(2) | 5.48(3) | Fe I .34(400) Nd II .36(100) (Nd II .55(20)) (Gd II .52(200)) (Gd II .09(80)) |
| 3805.65(1) | | | | | Sm II .63(200) |
| 3806.09(1) | | 6.10(1) | 6.09(1) | | |
| 3806.35(1) | 6.37(0) | | | 6.17(2) | Dy II .28(50) (Fe I .22(40)) |
| 3806.60(1) | 6.78(0) | 6.68(1n) | | 6.78(2) | Fe I .70(200) |
| 3806.95(2) | 7.02(2) | | | 7.05(1) | Fe II .82(pr) Nd II .23(15) (Tb(II?) .85(S50)) |
| 3807.52(1) | 7.51(1) | 7.49(1) | 7.61(1) | 7.54(1) | Fe I .54(150) Cr II .34(1) (Eu II .54(30)) (Gd II .65(25)) (Zr II .41(2)) |
| 3808.08(1) | 8.17(1) | 8.07(1n) | 8.09(0) | 8.22(1) | Ce II .12(300) |
| 3808.62(0) | | | | | |
| 3809.06(2n) | | | 8.80(1) | 8.89(2) | Nd II .05(25) Nd II .77(30) Fe I .73(100) Dy II .04(25) |
| 3809.42(0) | 9.19(0) | 9.14(1) | 9.35(1) | 9.34(1) | Cr II .54(1) Ce II .22(25) (Pr II .16(30)) (A II .49(25)) |
| | 9.76(0) | 9.74(0) | 9.81(1) | | |
| 3810.05(2) | 0.09(2) | | 0.22(0) | 9.89(2) | Cr II .05(1) |
| 3810.50(0) | | | | 0.31(0) | Nd II .48(40) |
| 3810.84(1) | 0.81(1n) | 0.69(1) | 0.74(1) | 0.72(2) | Cr II .74(1) Fe I .76(70) (Nd II .07(20)) (Ho(II?) .70(S40)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3811.41(0) | 1.52(0) | | | 1.46(0) | |
| | | 2.08(0) | | 1.97(0) | Nd II .77(20) |
| 3812.16(1) | 2.32(0) | | | 2.38(1n) | Sm II .07(150) Gd II .19(8) |
| 3812.77(2n) | 2.91(1) | 3.01(1) | 3.04(0) | 3.11(3) | Fe I .96(400) |
| 3813.34(3) | 3.45(2) | 3.39(1) | 3.40(1) | 3.50(2) | Ti II .39(20) |
| | | | | 3.84(0) | Dy II .68(40) Fe I .89(50) |
| 3814.03(6) | 4.08(5) | 4.01(5) | 4.04(4) | 4.07(5) | Fe II .12(4) Cr II .00(12) (Gd II .97(2000)) |
| 3814.63(2n) | 4.64(2) | 4.64(2) | 4.59(1) | 4.64(4) | Ti II .58(35) Fe I .52(80) |
| 3814.82(2n) | 4.81(1) | | | | Nd II .72(60) Zr II .97(2) (Gd II .74(100)) |
| | | 5.06(0) | | 5.07(0) | |
| 3815.21(0) | 5.36(0) | 5.35(1) | 5.38(0) | 5.44(1) | V II .38(200) Eu II .50(80) |
| 3815.74(5) | 5.81(4) | 5.82(4) | | 5.81(1n) | Fe I .84(700) Cr II .77(2) (Ce II .83(250)) |
| | | | 5.95(3n) | 6.03(5n) | |
| 3816.28(2n) | 6.28(1) | | | 6.24(1) | Pr II .17(125) (La II .25(10)) |
| 3816.83(3) | 6.82(1) | 6.53(1n) | 6.63(2) | 6.68(5) | Dy II .77(200) Gd II .64(250) |
| 3817.26(1) | 7.35(2) | 7.33(2n) | | | Nd II .37(15) La II .24(8) (Tm II .40(100)) |
| 3817.47(1) | 7.57(1) | | 7.41(1n) | 7.47(4n) | Ce II .46(25?) Fe I .65(50) (Zr II .59(12)) |
| 3817.88(0) | 7.92(1) | | 7.81(1) | 7.72(1) | Pr II .87(30) |
| 3818.24(1) | 8.32(1) | 8.08(1) | 8.19(1) | 8.28(2) | Pr II .28(125) Y II .34(50) (Ne II .44(25)) |
| 3818.85(2) | 8.81(1) | 8.68(0) | 8.80(2n) | 8.76(3) | Gd II .75(150) |
| 3819.16(0) | | | | 9.14(1) | |
| | 9.42(1) | 9.47(1) | | | |
| 3819.73(6) | 9.77(2) | 9.69(1) | 9.55(3) | 9.59(9) | Eu II .67(6000) |
| | | | 0.06(0) | 0.19(1) | |
| 3820.38(4n) | 0.39(5) | 0.38(5) | 0.41(3) | 0.51(2n) | Fe I .43(800) Cr II .48(2) |
| 3820.61(0) | 0.95(1) | | 0.86(1) | 0.94(2) | Ce II .87(5?) |
| 3821.08(2) | 1.16(2) | 1.15(1n) | 1.25(2) | 1.32(1) | Fe I .18(100) |
| 3821.86(3) | 1.93(2) | 1.85(2) | 1.88(3) | 1.93(3) | Pr II .82(50) Fe I .84(50) (Fe II .92(pr)) |
| | 2.29(0) | | | | Gd II .17(80) |
| | | 2.40(0) | | 2.47(1) | Nd II .47(20) |
| 3822.61(1) | 2.61(1) | | 2.67(1) | | Dy II .59(20) |
| | | | | 2.76(2) | Fe II .74(3) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3822.90(1) | 3.00(0) | 3.00(0) | 3.08(1) | | (Gd II .20(12)) (Pr II .18(75)) |
| 3823.41(1n) | 3.41(0n) | | | 3.37(1n) | Pr II .57(10) (Zr II .41(3)) |
| 3823.86(1) | 3.87(1) | 3.84(0) | | | Ce II .90(50) (Zr II .72(1)) |
| 3824.31(3n) | 4.39(1) | 4.31(2) | 4.36(1) | 4.41(2n) | Fe I .44(150) |
| 3824.84(3) | 4.97(2) | 4.89(2) | 4.94(3) | 5.03(4) | Fe II .91(4) (Gd II .02(50)) |
| 3825.26(1) | 5.34(2) | 5.40(1) | 5.39(1) | 5.44(1) | |
| 3825.77(5n) | 5.84(3) | 5.86(4) | 5.88(4) | 5.98(7) | Fe I .88(500) Dy II .6(30) |
| 3826.12(2n) | 6.06(1) | | | | Sm II .20(400) Gd II .05(200) (Pr II .29(100)) (Dy II .0(20)) |
| 3826.35(0) | 6.38(0) | 6.42(1) | 6.55(1) | 6.51(1) | Nd II .42(60) |
| | 6.77(0) | | | 6.74(0) | Eu II .68(50) |
| 3826.99(2) | 7.06(2) | 7.06(3n) | 7.11(2) | 7.16(3) | Fe II .08 (4) Cr II .95(1) (Cr II .06(0)) |
| | | | | 7.55(1) | Gd II .33(80) (P II .44(150)) |
| 3827.70(4) | 7.82(3) | 7.78(3) | 7.90(1) | 7.90(2n) | Fe I .82(200) |
| 3828.22(2) | 8.36(1) | | 8.18(0) | 8.01(2) | Gd II .00(30) Nd II .99(30) |
| | | 8.58(0) | | 8.71(0) | (Gd II .69(6)) |
| 3829.00(0) | 8.95(0) | | | 9.02(0) | Fe II .86(2) Nd II .84(40) (Eu(II?) .93(30)) |
| | 9.28(0) | | | | Mg I .35(100) Nd II .15(30) |
| | | 9.87(0) | | | (Ne II .77(40)) |
| 3830.57(0) | 0.54(0) | | | 0.34(1) | Sm II .29(200) Nd II .48(20) (N I .39(150)) (A II .43(10)) |
| 3831.13(0) | | | | 1.08(1) | Gd II .98(30) |
| 3831.66(1) | | | 1.56(1) | 1.62(1) | Sm II .50(400) Dy II .64(20) |
| | | | | 2.16(0) | Mg I .31(250) (Gd II .80(100)) |
| | | | | 2.49(0) | Cr II .40(0) |
| 3833.03(0n) | | 2.90(0) | | 2.90(1) | Fe II .96(2?) Cr II .74(1) (Y II .89(80)) (Ce II .74(4?)) (Zr II .94(1)) (Fe I .31(100)) |
| | | 4.16(0) | | 4.12(0) | Fe I .22(400) (Sm II .83(200)) |
| 3835.48(xn) | 5.40(xn) | 5.32(xn) | 5.42(9n) | 5.40(xn) | H 9 .39(40) |
| | 6.68(0) | 6.83(0) | | 6.92(0) | Dy II .51(200) Gd II .91(300) Nd II .54(60) (Zr II .76(60)) |
| | | | | 7.34(0) | Cr II .51(1) Ce II .21(3) Cr II .63(0) (Ho II .45(15)) |
| | | 8.30(0) | 8.48(0) | | Mg I .26(300) Ce II .54(150) Eu II .24(30) (Zr II .28(5)) |
| | 8.94(0) | 8.76(0) | | | Sm II .94(200) Nd II .98(80) (Dy II .67(5)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification. |
|---|---|---|---|---|---|
| 3839.55(1) | 9.62(1) | 9.38(0) | 9.37(1n) | 9.50(0) | Gd II .64(300) Fe I .26(100) (Nd II .50(15)) |
| 3840.14(0) | | | 9.95(1) | | |
| 3840.35(1n) | 0.49(1n) | 0.42(2) | 0.41(1) | 0.49(2) | Fe I .44(400) (La II .72(60)) |
| 3840.98(2n) | 1.06(2) | 1.02(2) | 1.09(1n) | 1.14(1) | Fe I .05(500) (Pr II .01(60)) |
| | | 1.60(0) | | | Dy II .32(100) |
| 3841.98(1n) | 2.08(1) | 2.09(1) | 2.08(1n) | 1.93(1n) | Al II .04(10) (Ho II .05(4)) |
| | 2.41(0) | | | 2.28(0) | Gd II .20(400) Pr II .36(60) Cr II .45(1) (Eu II .35(8)) (Tb II .49(40)) (Cr II .66(1)) |
| | 3.09(1n) | 3.06(1n) | 2.95(1) | 3.02(1) | Mn II .98(1) Zr II .03(30) |
| 3843.14(2) | 3.17(0) | | 3.24(0) | 3.20(1n) | Fe I .26(125) Gd II .27(500) (Eu II .15(50)) |
| 3843.65(0) | | 3.68(0) | | 3.42(1) | Sm II .50(200) |
| 3843.97(1n) | | | | 3.92(1) | Gd II .80(25) (Ho II .86(8)) |
| 3844.19(1n) | 4.16(1) | 4.15(1) | | 4.12(0) | Eu II .23(8) |
| 3844.67(2) | 4.67(1) | 4.64(0) | 4.43(1) | 4.54(1) | Gd II .58(500) (Pr II .56(60)) |
| | | 4.83(1n) | | | |
| 3845.10(2) | 5.22(2) | 5.24(2) | 5.28(1) | 5.29(3) | Fe II .18(4) Fe I .17(100) (Cr II .16(1)) |
| 3845.52(1) | | | | | Gd II .47(20) Co I .47(500) (Cl II .42(50)) |
| 3845.74(1) | 5.66(1) | 5.72(0) | 5.69(1n) | 5.79(1) | (Cl II .82(30)) (Cl II .68(75)) (Tb II .61(10)) |
| 3846.46(1n) | 6.38(0) | 6.44(0) | 6.51(0n) | 6.26(1) | Dy II .36(25) Fe I .42(50) |
| 3846.80(1n) | 6.79(1n) | 6.77(1) | | 6.65(2) | Fe I .80(125) Pr II .61(125) (Ho II .68(10)) |
| 3847.39(0n) | 7.33(0) | 7.44(1) | 7.47(0) | 7.35(0) | Sm II .51(150) V II .32(100) |
| | | | | 7.80(1) | Eu II .85(50) |
| 3848.07(1) | 8.18(1) | | | 8.23(0) | Tm II .02(1000) Mg II .24(10) (Nd II .23(50)) (Nd II .31(40)) |
| 3848.53(1) | 8.64(1) | 8.54(0) | 8.50(1) | 8.62(3) | Eu II .40(10) Ce II .60(150) Nd II .52(80) |
| 3848.76(1n) | 8.76(0) | | | | Sm II .78(200) Tb II .75(100) |
| 3848.93(1) | 9.07(0) | | | | La II .01(100) |
| 3849.44(3) | 9.43(2) | 9.52(1) | 9.43(0) | 9.28(2) | Dy II .40(20) |
| | 9.56(0) | | | 9.57(0) | Ni II .58(2) |
| 3849.87(1) | 9.93(1n) | 9.91(1) | | 9.81(0) | Fe I .97(500) |
| 3850.30(0) | | | | 0.20(1) | Mg II .40(5) Nd II .23(20) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 0.54(0) | 0.55(0) | | 0.54(1) | Gd II .69(800) (Dy II .45(4)) (Dy II .53(5)) |
| 3850.80(2n) | 0.87(2n) | 0.75(1) | 0.82(2) | 0.91(4) | Gd II .97(1200) Fe I .82(200) (Pr II .82(150)) (S II .93(8)) (Cl II .02(100)) |
| 3851.32(1n) | | | | | (Cl II .42(75)) (Ho II .4(4)) |
| 3851.70(1n) | 1.60(1n) | 1.43(0) | 1.60(1) | 1.52(1) | Pr II .62(200) (Nd II .75(60)) (Nd II .66(30)) (F II .67(200)) |
| | | | 1.95(1) | 1.95(0) | Sm II .88(150) (Tb II .86(5)) |
| 3852.16(1) | 2.18(0) | 2.15(0n) | | | |
| 3852.52(2) | 2.49(1) | 2.40(1) | 2.40(1) | 2.42(2) | Gd II .45(1000) Fe I .58(150) (Cr II .61(1)) |
| 3853.07(4) | 3.14(2) | | 2.85(1) | 2.93(3) | Dy II .04(100) Ce II .16(125) (Pr II .80(150)) (Zr II .07(2)) |
| 3853.63(8) | 3.64(8) | 3.62(8) | 3.65(3) | 3.58(5n) | Si II .67(3) |
| | 4.03(0) | | | | Ho II .08(20) |
| 3854.25(4) | 4.35(2) | 4.17(1) | 4.22(1) | 4.19(1n) | Sm II .21(300) Ce II .19(100) Ce II .32(100) |
| 3854.70(1) | | 4.53(0) | 4.79(0) | 4.75(1) | Cr II .73(2) Eu II .64(20) |
| 3854.97(1) | 4.95(1n) | | | | Pr II .90(100) Fe II .13(0) Cr II .86(2) (La II .91(30)) (Eu II .81(20)) |
| 3855.59(0) | 5.46(0) | 5.50(0n) | 5.43(1n) | 5.45(1) | Gd II .56(200) (Tb II .58(10)) (Zr II .43(3)) |
| 3855.99(x) | 6.00(9) | 5.99(x) | 5.97(6) | 5.99(9) | Si II .03(8) |
| | 6.39(1) | 6.50(1) | 6.43(1) | 6.53(1) | Fe I .37(500) |
| 3856.69(1) | 6.75(0) | 6.94(1) | 6.98(2) | 6.88(2) | Cr II .93(2) Ce II .03(5) (Ho II .98(8)) |
| 3857.11(0) | 7.19(0) | | | 7.39(0) | Cr II .19(1) Ce II .24(4?) |
| 3857.69(0) | 7.68(1n) | 7.55(1) | 7.64(1) | 7.71(1) | |
| | | | | 8.02(0) | Sm II .91(100) |
| 3858.18(0) | 8.19(0) | | 8.17(0) | 8.29(1) | Pr II .26(30) Ni I .30(800) |
| 3858.49(1) | 8.51(1) | | | 8.54(1) | |
| 3858.80(0) | 8.89(1) | 9.00(0) | 9.03(0) | | |
| 3859.29(2) | 9.36(1) | 9.30(1n) | 9.46(1) | 9.16(1) | Cr II .38(1) Fe I .22(100) (Al II .33(10)) |
| | 9.73(1) | | | 9.62(0) | |
| 3859.82(5) | 9.93(3) | 9.89(3) | 9.90(2) | 0.02(3) | Fe I .91(1000) |
| 3860.23(0) | 0.19(0) | | | | |
| | 0.51(1) | 0.57(0) | 0.69(1n) | | (S II .64(15)) |
| 3860.80(2n) | 0.78(1) | | | 0.84(3n) | Fe II .92(3) Eu II .73(10) (Cl II .99(100)) (Cl II .83(150)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3861.23(1n) | 1.26(1) | | | 1.26(1) | Eu II .18(80) Gd II .14(50) Fe I .34(80) Cr II .34(1) (Pr II .31(30)) |
| 3861.68(0) | 1.75(1) | | 1.70(1) | 1.73(0n) | Ho II .68(40) |
| 3861.99(1) | 2.04(3) | | | | Sm II .05(150) |
| 3862.57(x) | 2.59(9) | 2.56(x) | 2.52(7) | 2.56(8) | Si II .60(6) (Nd II .49(15)) |
| | 3.13(1) | 3.14(1) | 3.07(1) | | Gd II .05(150) |
| 3863.28(5) | 3.40(2) | 3.42(1) | 3.31(2n) | 3.38(2n) | Fe II .41(1) Cr II .46(1) Nd II .41(60) (Nd II .33(20)) |
| 3863.91(4n) | 3.95(2) | 3.96(3) | 3.94(3) | 4.01(3) | Fe II .95(1) Eu II .11(40) (Mo I .11(1000)) |
| 3864.59(1) | 4.67(1) | | 4.47(1) | 4.57(2) | La II .49(100) |
| 3864.98(1) | 5.02(1) | 4.83(1) | 4.98(1) | 5.01(1) | (Eu II .29(15)) |
| | | 5.43(2) | | 5.44(1) | Pr II .46(100) Dy II .45(8) |
| 3865.50(5) | 5.58(4) | 5.61(4) | 5.58(5) | 5.68(4) | Cr II .59(75) Fe I .53(600) |
| 3865.90(2) | 6.04(2) | 6.02(1) | 6.04(2) | 6.12(1) | Cr II .01(5) Nd II .99(10) |
| | 6.33(0) | | | | Eu II .19(20) |
| 3866.41(2) | 6.56(2) | 6.50(2) | 6.53(3) | 6.57(3) | Cr II .55(7) Dy II .59(30) (Nd II .52(15)) |
| 3866.68(1) | 6.91(0) | | | | Nd II .80(10) |
| 3867.15(1) | 7.22(1) | 7.05(1) | 7.09(1) | 7.06(2) | Fe I .22(150) Gd II .26(60) |
| 3867.48(0) | | | | | Pr II .55(30) |
| 3867.89(1) | 7.68(1) | | 7.62(1) | 7.72(2) | Cr II .80(1) Cr II .86(1) (Dy II .84(5)) |
| 3868.49(2) | 8.44(1) | 8.32(1) | 8.35(1) | 8.40(3n) | Cr II .32(2) Dy II .45(50) (La II .35(3)) |
| 3869.11(1) | 9.17(1) | 9.03(0) | 8.96(1) | 9.10(2n) | Nd II .04(30) |
| | | | | 9.28(2) | |
| 3869.48(2) | 9.61(1) | 9.47(0) | 9.70(0) | 9.71(1) | Cr II .62(2) Dy II .43(60) Fe I .56(100) |
| 3869.91(1) | 9.92(1) | | | 9.95(0) | Dy II .87(60) (Tb II .75(15)) |
| 3870.23(0) | | | | 0.16(0) | |
| 3870.62(2n) | 0.64(1) | | 0.43(1) | 0.40(1) | |
| 3870.96(1) | | | 0.96(0) | 0.85(1) | |
| 3871.37(0) | | | | 1.24(0) | |
| 3871.57(1n) | 1.56(1) | 1.56(1n) | 1.51(1) | 1.60(2) | Gd II .54(80) La II .63(200) Sm II .78(300) Cr II .76(1) (Dy II .64(30)) (Fe I .75(100)) |
| | 1.85(0) | | | | Cr II .85(1) |
| 3872.15(1) | 2.19(1) | | 2.01(1) | 2.03(2) | Dy II .12(600) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3872.46(0) | 2.51(1) | 2.58(2n) | 2.55(1) | 2.56(2) | Fe I .50(300) Cr II .57(1?) |
| 3872.68(3) | 2.77(3) | 2.71(3) | | 2.72(2) | Gd II .62(60) Fe II .76(pr) |
| 3873.28(1) | 3.39(0) | | 3.02(0) | 3.15(1) | Gd II .32(15) |
| | | | | 3.53(0) | Cr II .51(2) |
| 3873.86(1) | 3.71(1) | 3.70(1) | 3.82(1) | 3.89(2) | Dy II .00(60) (Tb II .78(8)) |
| 3874.32(0) | 4.25(1) | 4.43(1) | 4.56(1) | 4.58(2) | Pr II .45(25) Cr II .41(pr) Tb II .18(200) (Ho II .11(2)) |
| 3874.72(2) | 4.73(1) | | | | Ho II .70(6) Cr II .76(pr) |
| | 5.12(1) | | 5.20(1n) | 5.11(1) | Sm II .19(100) Eu II .10(8) Ce II .04(6d?) (Dy II .15(4)) (Tb II .21(20)) (A II .26(25)) |
| 3875.34(0) | 5.46(0) | | | | Gd II .46(100) Sm II .55(200) |
| 3875.71(3) | 5.77(1) | | | 5.58(3) | Nd II .87(40) Nd II .74(20) |
| | | | | 5.98(0) | (Fe I .04(40)) |
| 3876.17(2) | 6.25(1) | 6.10(0) | 5.99(1n) | 6.25(2n) | Pr II .18(50) |
| 3876.63(1) | 6.68(1) | | 6.46(1) | 6.53(1) | Lu II .65(100) |
| 3877.28(1) | 7.15(1) | 7.10(1) | 7.13(1) | 7.24(3n) | Cr II .26(2) Eu II .27(40) (Ce II .97(15)) (Pr II .22(200)) |
| 3877.63(0) | 7.42(1) | 7.56(0) | | 7.42(0) | Cr II .48(1) (Tb (II?) .56(6)) |
| | 7.74(0) | | | | Eu II .88(10) |
| 3877.99(1) | 7.96(1) | 7.98(1) | 7.83(1) | 7.88(2) | Fe I .02(400) (Dy II .94(2)) |
| 3878.54(1) | 8.53(1) | 8.55(1) | | 8.68(1) | Fe I .58(300) Ce II .37(150) Nd II .58(50) |
| | 8.71(2) | 8.92(0) | 8.84(1) | 8.95(2) | V II .72(300) (Fe I .68(30)) |
| 3879.13(3) | 9.21(1) | 9.13(0) | | | Dy II .05(30) Pr II .21(25) |
| 3879.64(1) | 9.69(1) | 9.55(0) | 9.47(0) | 9.60(1) | Nd II .54(40) |
| 3880.29(1) | | 0.24(0) | | 0.13(0) | Nd II .38(30) (Pr II .47(100)) |
| 3880.76(2) | 0.77(0) | | 0.50(0n) | 0.70(2) | Pr II .47(100) Fe II .78(1) Sm II .77(150) Cr II .80(2) (Nd II .78(40)) (Nd II .37(30)) |
| 3881.51(1) | 1.60(0) | | 1.21(0) | 1.37(2) | Cr II .36(2) Sm II .38(100) |
| 3881.93(0) | | | 1.78(1) | 1.92(2) | Gd II .84(50) Dy II .00(20) Gd II .94(30) (Ni II .92(1)) (Zr II .97(7)) |
| 3882.46(2n) | 2.44(1) | 2.25(1) | 2.33(1) | 2.39(3) | Ce II .45(75) |
| 3882.98(1) | | 3.19(0) | 3.35(0) | 3.04(1) | Mn II .28(3) Fe I .29(70) (Dy II .06(4)) |
| 3883.52(0) | | | | 3.59(1n) | Eu II .64(20) Tm II .44(200) |
| 3884.63(0) | | | | 4.47(0n) | Gd II .66(15) |
| 3885.35(0) | | | | 5.27(0) | Sm II .29(1000) Pr II .19(75) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3886.16(0) | 6.35(0) | 6.19(0) | 6.26(1) | 6.29(1) | Fe I .28(600) La II .37(150) (Ho II .4(6)) |
| | | | 6.86(1n) | 6.96(0) | Gd II .16(40) Tb II .83(20) (Cr I .79(125)) |
| | | | | 8.06(0) | Nd II .87(30) |
| 3889.08(xn) | 9.04(xn) | 9.00(xn) | 8.99(xn) | 8.99(xn) | H8 .05(60) (Dy II .99(20)) |
| 3889.78(0) | | | | 9.93(1) | Ce II .99(300) Nd II .66(20) Nd II .93(50) (Tb II .85(10)) |
| 3890.16(0) | | | | | Sm II .08(200) Nd II .22(8) |
| 3891.10(0) | | 0.85(0) | 0.77(0) | 0.90(1) | Gd II .85(30) Cr II .86(1) Ho II .02(200) Nd II .94(60) (Fe I .84(60)) |
| | | | | 1.53(1) | Nd II .51(20) Pr II .70(12) |
| 3892.06(0n) | 2.13(1) | 2.11(0) | | 2.14(1) | Cr II .14(4) Fe I .93(100) (Dy II .85(3)) (Nd II .06(10)) (La II .05(3)) |
| | | | | 2.65(0) | (La II .47(3)) |
| 3893.09(1n) | | 3.10(0) | | 3.03(1) | (Ho II .10(4)) |
| | 3.33(0) | | | 3.39(0) | Fe I .39(100) Cr II .31(1) Cr II .52(1) (Tb II .35(15)) (Ho II .54(5)) |
| 3893.89(0) | 3.96(1) | 3.98(0) | | 4.00(1) | (Co I .08(1000)) |
| 3894.54(0) | 4.57(0) | 4.55(1) | 4.54(1) | 4.67(1) | Gd II .70(2000) (A I .66(300)) (Nd II .63(40)) (Cr II .77(1)) |
| 3895.03(0) | 5.16(1n) | 5.14(1) | 5.18(2) | 5.22(4) | Gd II .23(200) Cr II .16(2) Ce II .11(125) (Pr II .08(10)) |
| 3895.38(1) | | 5.54(1) | | | Dy II .35(25) Nd II .38(3) (Ho II .53(4)) |
| | | 5.90(0n) | | 5.77(2) | Gd II .79(400) Fe I .66(400) |
| 3895.96(2) | 6.04(1) | 6.12(1) | 5.95(0n) | 6.14(2) | Nd II .14(10) V II .16(60) Tb II .04(25) |
| 3896.34(1) | | | | | Gd II .42(10) |
| 3896.83(2) | 6.89(2) | 6.72(1n) | 6.64(1) | 6.78(4) | Ce II .80(100) Cr II .62(1) (Pr II .84(10)) (Ho II .75(5)) (Tb II .60(25)) |
| | | | 7.07(0) | 7.19(1) | Sm II .98(600) Pr II .04(12) |
| 3897.42(0) | 7.55(1n) | 7.51(1) | | 7.37(1) | Pr II .28(25) (Tb II .39(4)) (La II .43(4)) (Ho II .27(4)) |
| | 8.13(1) | 8.02(1) | 8.13(1) | 7.97(1) | Fe I .01(80) Ce II .27(100) (Fe I .90(100)) (Cr II .81(1)) (Eu II .25(10)) |
| 3898.51(4n) | 8.60(3) | 8.56(1) | 8.42(1) | 8.42(5) | Dy II .54(500) Cr II .49(1) Gd II .40(10) |
| 3899.03(1) | 9.18(1) | 9.27(0) | | 8.93(2) | V II .14(200) Cr II .80(0) (Pr II .84(10)) (Tb II .19(200)) |
| 3899.58(1) | 9.47(0) | | | | Eu II .49(10) (Tb II .54(15)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3899.69(1) | 9.77(1) | 9.67(1n) | 9.75(0n) | 9.62(1) | Fe I .71(500) Cr II .95(2) (A I .86(100)) |
| 3900.17(0) | 0.34(0) | | | | Eu II .18(10) Nd II .23(60) |
| 3900.51(7) | 0.56(4) | 0.51(3n) | 0.45(3) | 0.50(6) | Ti II .54(50) (Fe I .52(60)) |
| 3900.66(1) | | | | | Al II .68(200) Cr II .81(1) (Tm II .79(90)) |
| 3901.15(1n) | 1.34(1) | | 1.04(0) | 1.04(0) | Cr II .29(0) |
| 3901.71(2) | 1.75(1n) | 1.53(1n) | 1.46(1n) | 1.55(3) | Nd II .85(50) (Eu II .63(3)) (Tb II .60(6)) |
| 3902.02(0) | | | | 1.99(0) | (Tb II .98(15)) |
| | | 2.21(0n) | | 2.25(1) | (Ho II .24(4)) |
| 3902.38(2) | 2.49(1) | | 2.36(1n) | 2.62(2) | Gd II .40(1000) Pr II .47(25) (Dy II .39(2)) (Tb II .35(10)) |
| 3902.89(2) | 2.98(2) | 2.95(1) | 2.97(1) | 3.02(2) | Fe I .95(500) (Mo I .96(1000)) |
| 3903.17(1) | 3.28(1) | | 3.30(0) | 3.42(1) | V II .27(250) Sm II .42(500) |
| 3903.66(2) | 3.79(3) | 3.73(2) | 3.78(3) | 3.82(3) | (Zr II .77(1)) |
| 3903.99(1) | | | | | Fe I .90(100) Cr II .15(1) (Dy II .14(20)) |
| 3904.47(0) | 4.49(0) | 4.48(1n) | 4.32(0) | 4.47(1) | (Ce II .34(5?)) |
| 3904.83(1) | 4.74(0) | | | 4.76(1) | |
| 3905.20(0) | 5.04(0) | | 5.01(0) | | |
| | | | | 5.41(2) | Si I .53(20) |
| 3905.54(6) | 5.61(8) | 5.58(3n) | 5.65(4) | 5.72(3) | Cr II .66(25) (Si I .53(20)) (Dy II .56(2)) |
| 3906.00(4) | 6.06(4) | 6.05(3n) | 6.08(4) | 6.16(5) | Fe II .04(5) Nd II .89(100) (Ho II .78(30)) (Nd II .10(10)) |
| 3906.43(1) | 6.41(1) | | 6.52(0) | 6.50(1) | Fe I .48(300) |
| 3906.86(0) | 6.91(1) | | | | |
| 3907.21(7) | 7.15(2n) | 7.10(3) | 6.94(2n) | 7.02(7) | Eu II .10(3000) |
| | | | 7.30(1) | 7.37(1) | Ce II .29(125) Cr II .36(1) (Sc I .48(125)) |
| 3907.63(0) | | | | 7.69(1) | Tb II .65(3) Tb II .79(3) (Ti II .65(pr)) |
| 3907.98(3) | 8.08(2n) | 8.07(2n) | 8.02(3) | 8.16(7) | Fe I .94(100) Pr II .03(150) (Gd II .14(8)) (Nd II .84(20)) |
| 3908.37(4n) | 8.51(3n) | | 8.45(2) | 8.51(3) | Pr II .43(200) Ce II .41(125) |
| 3908.68(1) | | | | | Ce II .54(100) (Fe II .54(pr)) (Cr I .76(200)) (La II .79(15)) |
| 3909.14(1n) | 9.19(1) | 9.21(1n) | 8.97(0) | 9.04(1) | Cr II .17(1) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 9.32(1) | | 9.31(1) | 9.42(2) | Ce II .31(35) |
| 3909.59(1n) | 9.78(1n) | | 9.88(0) | 0.03(1) | Pr II .62(8) (Fe I .84(40)) (Tb II .13(4)) |
| 3910.23(1) | 0.27(0) | 0.53(1) | 0.46(1) | 0.42(1) | Gd II .20(6) Cr II .44(1) |
| 3910.67(1) | 0.74(1) | | | 0.78(1) | Fe I .84(30) (Tb II .57(2)) (La II .81(10)) |
| | | | | 1.15(0) | Nd II .17(60) |
| 3911.19(1) | 1.34(3) | 1.35(2) | 1.39(3) | 1.45(5) | Cr II .32(3) |
| 3911.53(0) | | | | | Cr II .54(2) |
| 3911.73(1n) | 1.67(1) | | | | (Sc I .81(150)) |
| 3912.22(0n) | 2.27(1) | 2.11(0) | 2.04(1n) | 2.09(2) | Nd II .23(20) Ce II .19(5) (O II .95(150)) |
| 3912.36(1n) | 2.55(1) | 2.47(1n) | 2.54(2) | 2.47(2) | Ce II .42(300) |
| 3912.78(1n) | 2.99(1) | | | 2.70(2) | Pr II .90(125) (Tb II .78(5)) (Dy II .85(3)) |
| | 3.23(0) | | | | Cr II .20(2) |
| 3913.44(3) | 3.56(3) | 3.44(2) | 3.44(4) | 3.43(4) | Ti II .46(70) Cr II .48(1) (Fe I .64(100)) (Nd II .69(8)) (Pr II.56(15)) |
| 3914.06(1) | 3.82(0) | | 3.91(1) | 3.91(2) | Eu II .72(10) Gd II .78(20) Cr II .76 (2) Cr II .13(2) Ho II .96(3) Dy II .95(6) Cr II .96(1) (Cl II .92(30)) |
| | 4.29(1) | | | | Cr II .13(12) |
| 3914.40(2) | 4.49(2) | 4.43(1) | 4.58(2) | 4.63(1) | Fe II .48(2) (A II .76(25)) (Pr II .76 (8)) (V II .33(250)) (Zr II .36(7)) |
| 3914.93(2) | 4.98(1) | | 4.99(0) | 4.98(0) | Dy II .88(40) Ce II .95(18) (Nd II .13(8)) |
| 3915.51(1) | 5.48(1n) | 5.30(1n) | 5.42(2) | 5.49(3) | Dy II .60(40) Cr II .58(1) (Pr II .47(10)) (Eu II .24(15)) |
| 3916.08(0) | | 5.95(1) | 5.83(1) | 5.98(1) | Zr II .94(25) Nd II .95(20) (La II .05(300)) |
| 3916.65(3) | 6.62(1n) | 6.50(1) | 6.41(2) | 6.55(4) | Gd II .51(3000) V II .42(200) |
| | | | 6.77(0) | | Fe I .73(100) |
| | | | | 7.00(1) | Fe I .18(150) |
| 3917.43(1n) | 7.40(1) | 7.44(1n) | 7.23(1) | 7.32(1) | Eu II .29(60) Sm II .44(200) (Pr II .23(20)) |
| | | | 7.61(1) | 7.69(1) | Eu II .70(10) |
| 3918.19(2) | 8.24(2n) | | 8.07(0) | 8.15(1) | Gd II .06(150) Gd II .24(150) |
| 3918.47(2n) | 8.42(3) | 8.41(2n) | 8.46(1n) | 8.44(2) | Mn II .32(3) Ce II .28(200) (Dy II .54(4)) (Fe II .51(pr)) |
| | | 8.69(1) | | | (Fe I .65(60)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.460 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 9.00(1) | | | 8.98(1) | Eu II .09(15) Pr II .86(150) (Tb II .82(8)) |
| 3919.39(2n) | 9.44(2n) | 9.31(1) | 9.31(0) | 9.36(2) | (? 0 II .28(35)) (Tb II .54(40)) |
| 3919.82(0) | 9.86(1) | | | 9.67(0) | Ce II .81(100) Nd II .92(10) (Pr II .62(25)) |
| 3920.14(2) | 0.22(2n) | 0.05(1) | 0.19(1n) | 0.03(2) | Fe I .26(500) (Gd II .99(6)) |
| 3920.57(2) | 0.68(3n) | 0.57(2) | *0.63(3) | 0.70(3) | (C II .68(200)) (Pr II .52(15)) (Tb II .72(10)) |
| 3920.80(0) | 1.05(1) | 1.22(0) | 1.05(1) | 1.17(1n) | Nd II .96(100) |
| 3921.38(0n) | 1.41(0) | | 1.33(0) | 1.51(0) | (La II .54(200)) |
| 3921.87(1) | 1.87(1) | 1.86(1n) | 1.86(1n) | 1.82(1) | Ce II .73(100) Ce II .00(2?) |
| | 2.00(3) | | 2.11(1) | 2.21(0) | Tb II .09(20) |
| 3922.46(0) | | | 2.48(1) | 2.35(1) | Sm II .40(800) (Zr II .36(1)) |
| 3922.86(1) | 2.89(1) | 2.88(1n) | | 2.84(0) | Fe I .91(600) Tb II .74(50) |
| 3823.37(4) | 3.43(1) | 3.42(0) | 3.13(3) | 3.21(5n) | Gd II .25(300) Gd II .33(80) Ce II .11 (125) (S II .48(200)) (Dy II .39(30)) (Dy II .30(3)) (Tb II .33(6)) (Ho II .37(5)) |
| | 3.80(0) | 3.89(1) | 3.85(1n) | 3.90(1) | |
| 3923.99(1) | 4.03(1) | | 4.23(0) | 4.28(1) | Pr II .14(10) |
| 3924.50(1) | | | | 4.36(1) | Ce II .64(60) Tb II .40(4) (Nd II .48 (8)) (Dy II .46(2)) (Ti I .53(70)) |
| 3924.80(1) | 4.80(1) | 4.77(1) | 4.82(2n) | 4.89(3) | Tb II .81(10) |
| 3925.46(1) | 5.51(1) | 5.39(1) | 5.47(2) | 5.53(2n) | Tb II .45(150) Pr II .46(75) (Fe I .65(80)) |
| 3925.96(0) | 6.14(0) | 6.01(1) | 5.98(1n) | 6.05(1) | (Fe I .95(50)) (Tb II .09(1)) |
| 3926.47(0n) | 6.67(1) | 6.76(1) | 6.58(1) | 6.73(1n) | |
| 3927.30(0) | | | | 7.17(0) | Nd II .11(40) Tb II .15(4) |
| 3927.42(1) | 7.54(0) | 7.37(1) | 7.44(1n) | 7.53(1) | Pr II .45(30) (Ce II .38(4)) |
| 3927.88(2) | 7.99(1) | 7.99(1) | 7.94(1n) | 7.86(1n) | Fe I .92(500) (Pr II .71(8)) |
| 3928.36(1) | 8.43(0) | | 8.44(0) | 8.44(0) | Sm II .28(400) |
| 3928.82(1n) | | | 8.56(1) | 8.74(0) | Eu II .87(15) Pr II .62(10) Pr II .91(10) |
| | | 9.09(1) | 9.14(2n) | | Pr II .26(20) (Ti II .15(pr)) |
| 3929.35(1n) | 9.32(0n) | | 9.30(2n) | 9.29(3n) | La II .22(300) Cr II .52(1) (Nd II .26 (15)) (Dy II .33(15)) (Zr II .54(8)) |
| 3929.80(1) | 0.09(1) | 9.84(1) | 9.80(1) | 9.98(1) | Eu II .91(6) V II .73(50) (Ti I .88(70)) |

* Phase 4.490 begins at wave length 3920.6

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3930.27(3) | 0.33(3) | 0.32(3) | | | Fe I .30(600) (Fe II .31(pr)) |
| 3930.61(8) | 0.69(3) | 0.69(0) | 0.37(5) | 0.45(9) | Eu II .48(4000) |
| | | | 0.63(1n) | 0.68(0n) | Tb II .76(8) |
| 3930.99(1) | | | 0.96(0) | | Cr II .88(pr) |
| 3931.34(1) | 1.17(1) | 1.13(1) | 1.28(2n) | 1.36(3n) | Ce II .09(125) Ce II .37(100) Dy II .29(20) (Fe I .12(35)) |
| 3931.50(2) | 1.62(1) | | | | Dy II .54(150) |
| 3931.99(1) | 2.14(2) | 2.01(1) | 2.02(3) | 2.10(4n) | Ti II .02(30) (S II .94(15)) |
| 3932.30(0) | 2.30(0) | | | | Dy II .23(20) |
| 3932.58(0) | 2.70(1) | 2.54(1) | 2.62(1n) | 2.60(1) | Fe I .63(80) (A II .55(25)) (La II .53(10)) |
| 3933.03(1) | 3.09(1) | | 2.81(0n) | 2.86(1n) | Gd II .98(50) Dy II .98(5) (S II .29(80)) |
| 3933.62(9) | 3.63(9) | 3.62(8) | 3.64(4n) | 3.61(8n) | Ca II .67(600) (Fe I .61(200)) (Ce II .73(60)) |
| 3934.17(2) | 4.21(1) | 4.29(1) | 4.10(1) | 4.06(3) | Zr II .14(20) Dy II .17(20) (Nd II .09(6)) |
| 3934.87(2) | 4.97(2) | 4.83(1n) | 4.71(2) | 4.74(3) | Gd II .82(300) Zr II .80(20) Nd II .82(50) Cr II .18(pr) |
| 3935.36(1) | 5.41(1) | 5.04(0) | 5.15(1) | 5.23(2) | Tb II .25(50) (Fe I .31(40)) |
| | | | | 5.66(1) | Sm II .76(150) |
| 3935.85(3) | 5.93(4n) | 5.92(4) | 5.96(5) | 6.02(6) | Fe II .94(6) Fe I .82(100) (Pr II .82(25)) |
| 3936.06(2) | | | | | Cr II .13(1) Dy II .03(15) Zr II .07(7) (Nd II .14(10)) |
| 3936.39(1) | 6.43(0) | 6.49(1) | 6.43(2) | 6.31(0) | La II .22(50) Ho II .51(10) Dy II .29(4) |
| 3936.83(3) | 6.89(2) | 6.92(1) | | 6.73(3) | Cr II .95(1) |
| 3937.19(1) | 7.12(0) | | 7.18(1) | 7.24(1) | Fe I .33(80) |
| 3937.63(3) | 7.66(1) | 7.71(1n) | 7.73(1) | 7.88(2) | Cr II .61(1) Nd II .58(5) |
| | | | 8.07(0) | 8.14(1) | Gd II .11(40) Dy II .06(4) (Ce II .09(7)) (Tb II .16(3)) |
| 3938.15(5) | 8.39(5) | 8.28(3) | 8.36(2n) | 8.46(3) | Fe II .29(2) (Pr II .31(15)) |
| 3938.57(0) | 8.73(1) | | | | |
| 3938.87(6) | 8.98(5) | 8.95(4) | 8.99(2n) | 9.01(2) | Fe II .97(4) Gd II .97(50) (Nd II .87(40)) |
| 3939.57(1n) | 9.63(1) | 9.51(0) | 9.46(1) | 9.55(1) | Tb II .60(200) (Nd II .55(8)) |
| | 0.07(0) | | 0.02(1n) | 0.94(1) | Pr II .15(20) La II .85(20) (Tb II .10(2)) |
| 3940.30(1n) | 0.46(1) | 0.26(0) | 0.30(1) | 0.36(1) | Ce II .34(100) (Ti II .32(pr)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| | | | 0.58(0) | 0.69(1) | Ho II .55(12) |
| 3940.83(1) | 0.90(1) | 0.89(0) | 0.94(0) | 1.05(0) | Fe I .88(150) Tb II .16(15) |
| 3941.32(0n) | 1.26(0) | 1.44(1) | 1.32(0n) | 1.35(0) | Fe I .28(60) (Tb II .35(4)) |
| 3941.54(1) | 1.57(0) | | | 1.62(0) | Eu II .56(20) Nd II .51(150) |
| 3942.13(2) | 2.10(2) | 2.09(1) | 2.16(1n) | 2.18(1) | Eu II .21(30) Sm II .87(300) Ce II .15 (125) Nd II .14(4) Dy II .05(4) Tb II .20(15) (Zr II .92(3)) |
| | 2.33(0) | | | 2.46(2n) | Fe I .44(100) Dy II .54(30) |
| 3942.67(2) | 2.80(1) | 2.66(0) | 2.77(1) | 2.85(1) | Ce II .75(150) (Nd II .63(6)) |
| 3943.09(1) | 3.22(1) | | 2.96(1) | 3.00(1n) | Eu II .08(40) Eu II .94(8) (Ce II .14(5)) |
| 3943.33(1) | | | 3.36(1) | | Sm II .24(200) Fe I .35(40) |
| | 3.53(0) | | | 3.52(1) | |
| 3943.77(1) | 3.93(1) | 3.80(0) | 3.92(1) | | Ce II .89(100) Cr II .64(1) (Mn II .82(1)) |
| 3944.10(1) | | | | 3.99(2) | Al I .03(2000) (Gd II .09(6)) |
| 3944.33(0) | 4.26(0) | | | | (A II .27(50)) |
| 3944.74(4) | 4.78(3) | | 4.51(1n) | 4.59(4) | Dy II .69(600) |
| 3945.09(1) | 5.19(3n) | 5.18(2) | 5.18(1n) | 5.09(1) | Cr II .11(1) (Fe I .13(30)) (Fe II .21(pr)) |
| 3945.35(1) | | | | 5.32(1) | |
| | 5.69(0) | | | 5.66(0) | Eu II .67(15) Pr II .66(10) |
| 3946.04(0) | 6.20(1) | 6.13(0) | 6.10(0) | 6.28(1) | (A II .10(25)) |
| 3946.47(0) | | | | 6.46(1n) | Sm II .51(200) |
| 3946.98(2) | 6.89(1) | 6.85(0) | 6.79(0) | 6.84(2) | Tb II .87(150) Fe I .00(50) Dy II .94(30) Ce II .68(20) |
| | 7.07(1) | | | | Fe I .00(50) |
| 3947.55(0) | | | 7.63(1) | 7.62(0) | Pr II .63(100) Fe I .53(70) (A I .50(1000)) |
| 3947.85(1n) | 7.94(0n) | | 7.98(0) | 7.95(1) | Sm II .11(300) Fe I .11(125) Sm II .84(100) |
| 3948.29(1) | 8.33(0) | | 8.52(1) | | Nd II .32(15) Tb II .35(20) |
| 3948.76(1) | 8.76(2) | 8.71(1) | 8.79(0) | 8.65(1) | Fe I .78(150) (Ti I .67(80)) |
| 3949.36(1n) | 9.45(1) | 9.35(1) | 9.37(1) | 9.50(1) | Pr II .44(125) Gd II .25(25) (Tb II .51(6)) |
| 3949.84(1) | 9.96(0) | | 0.16(2) | 9.87(0) | Fe I .96(150) Eu II .84(15) (Tb II .88(4)) |
| 3950.42(4) | 0.41(3) | 0.35(1) | 0.28(1n) | 0.28(4) | Dy II .40(30) Y II .36(100) |
| | | | | 0.48(1) | Y II .36(100) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3951.09(1) | 1.25(1) | 1.07(1) | 1.08(1) | 1.16(2n) | Nd II .15(150) Fe I .17(150) |
| 3951.44(0) | | | 1.41(0) | | (La II .43(3)) |
| 3951.83(1) | 1.71(0) | | | 1.71(0) | Tb II .71(3) |
| 3952.06(1) | 2.08(1n) | 1.97(0) | 1.93(1n) | 1.99(1n) | Gd II .00(300) V II .97(500) (Nd II .20(100)) |
| 3952.54(3) | 2.70(1) | 2.44(1) | 2.48(1) | 2.55(2n) | Ce II .57(125) Fe I .61(80) (Nd II .87(25)) |
| 3953.10(1) | 3.15(1) | | 3.03(0) | 3.05(1) | Fe I .16(80) |
| 3953.57(1) | 3.65(2) | 3.48(1n) | 3.48(1n) | 3.57(2) | Nd II .52(60) Pr II .52(125) Ce II .66(12) (Nd II .40(10)) |
| | | | | 4.05(1) | |
| 3954.20(0) | 4.30(2n) | | | | (O II .37(100)) |
| 3954.53(2n) | 4.53(2n) | 4.44(2n) | 4.38(2n) | 4.45(4) | (Dy II .56(25)) (O II .37(100)) |
| | | | 5.10(1n) | 4.93(0) | (Tb II .77(1)) |
| 3955.23(1n) | 5.38(1n) | 5.28(0) | 5.32(1n) | 5.36(2n) | (Fe I .35(25)) (La II .21(3)) |
| 3955.50(1n) | | | 5.71(0) | | (Gd II .70(6)) |
| 3955.88(0) | 6.09(0) | 6.06(0) | 5.93(1n) | 5.92(0) | Nd II .97(10) Gd II .14(8) |
| 3956.27(0) | 6.38(1) | | 6.31(1) | 6.18(1) | Ce II .28(150) Gd II .14(8) (Ti I .34(100)) (Tb II .16(8)) (La II .07(4)) |
| 3956.60(0) | 6.66(1n) | 6.63(1n) | 6.66(1) | 6.76(1) | Fe I .68(150) Fe I .46(100) (Pr II .76(20)) |
| 3956.89(0) | 6.99(1) | | 7.08(1) | | Ce II .90(4) Fe I .03(50) |
| 3957.40(0) | 7.38(0) | | 7.21(1) | 7.22(1) | (Nd II .47(15)) |
| 3957.85(4) | 7.92(3) | 7.87(1n) | 7.64(2) | 7.73(3) | Gd II .67(1000) Dy II .80(40) |
| 3958.26(2) | 8.22(2n) | 8.13(0) | 8.12(1n) | 8.08(2) | Cr II .07(1) Nd II .00(40) Tb II .97(40) Tm II .10(200) Eu II .92(15) Ce II .27(6) Zr II .24(50) (Ti I .21(150)) |
| | | | | 8.39(0) | Tb II .35(60) |
| 3958.82(1n) | 8.80(1) | 8.78(0) | 8.82(0) | 8.82(1) | |
| 3959.51(3n) | 9.44(1) | 9.48(1) | 9.35(2n) | 9.42(3n) | Gd II .52(500) Gd II .44(300) Sm II .53(100) (Dy II .35(3)) |
| | | | | 9.73(1) | Cr II .73(1) |
| 3960.36(1) | 0.27(0) | 0.33(0) | 0.27(1) | 0.49(1) | |
| 3960.81(3) | 0.90(2) | 0.81(2) | 0.90(2) | 1.00(2) | Fe II .90(3) (Ce II .91(125)) |
| 3961.63(1) | 1.60(1) | 1.47(1) | 1.41(1) | 1.49(2) | Al I .53(3000) |
| | 1.90(0) | 1.93(0) | 1.98(0) | | La II .03(10) |
| 3962.19(0) | | | 2.02(0) | 2.14(0) | Gd II .10(30) Nd II .22(15) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3962.56(1) | | | 2.66(0) | | Pr II .45(40) |
| 3962.99(0) | | | | 2.80(1) | Sm II .00(200) (Ti I .85(80)) (La II .04(5)) |
| 3963.08(2) | 3.06(1) | 3.08(0) | | 3.28(0) | Fe I .11(125) Nd II .11(60) |
| 3963.59(2) | 3.60(1) | 3.59(1) | | 3.70(0) | Gd II .66(150) Cr I .69(300) |
| 3963.83(0) | | | | | Nd II .91(20) Dy II .80(3) |
| 3964.19(0) | | | 4.29(0) | | Pr II .26(40) Ti I .27(80) (Nd II .19(5)) |
| 3964.50(0) | 4.49(1) | 4.62(1n) | | 4.58(0) | Fe I .52(80) Dy II .70(2) (Fe II .57(pr)) |
| 3965.11(0) | | | | 5.03(0) | Eu II .90(60) Pr II .82(250) (Eu II .02(15)) (Pr II .26(150)) |
| | 6.15(1) | | | | Sm II .04(150) Fe I .07(100) (Tb II .95(15)) |
| 3966.55(0) | | | | | Fe I .63(80) Pr II .57(80) (Eu II .59(81)) (Fe II .43(pr)) |
| | | | | 7.17(0) | Ce II .05(100) Nd II .07(15) (Gd II .85(4)) |
| 3967.38(0) | 7.54(1) | | | | Fe I .42(125) |
| 3968.36(1) | | | | | Dy II .40(1000) Gd II .26(60) (V II .11(150)) |
| 3968.51(4) | 8.48(3) | 8.46(4) | 8.29(3) | 8.36(8) | Ca II .47(500) (Dy II .40(1000)) |
| | | | | 9.00(0) | Fe I .26(600) (Gd II .29(300)) |
| 3970.14(xn) | 0.12(xn) | 0.10(xn) | 0.06(xn) | 0.03(xn) | H$_\epsilon$ .08 |
| | 1.02(1) | | | 1.02(0) | Gd II .06(100) Pr II .16(40) (Eu II .10(8)) |
| 3972.10(3) | 2.10(2) | 1.80(0) | 1.89(0) | 1.86(6) | Eu II .96(4000) Gd II .75(300) (Gd II .17(30)) (Pr II .69(25)) (Pr II .16 (100)) (Ce II .68(10)) (Tb II .05(20)) |
| | 2.52(1) | 2.44(0) | | 2.44(1) | |
| 3973.29(1) | 3.22(0n) | 3.37(0) | | 3.22(2) | Nd II .27(80) O II .27(125) (Ni I .56(800)) |
| | | | 3.70(0) | 3.75(1) | V II .64(300) Nd II .65(60) (Ni I .56(800)) |
| 3974.05(2) | 4.04(1n) | 4.11(2n) | 4.20(1) | 4.26(1) | Fe II .16(3) Gd II .98(500) (Tb II .30(15)) (Gd II .22(10)) |
| | | | | 4.62(1) | Fe II .54(1) |
| 3974.90(1) | 5.01(1n) | 4.96(2n) | 5.03(1) | 5.14(2) | Fe II .03(2) Gd II .11(60) (Pr II .86(15)) |
| 3975.35(0) | | 5.76(0) | 5.67(0) | 5.69(0) | |
| 3975.99(0) | 6.07(1n) | 6.15(1) | 6.25(1) | 6.20(0) | Sm II .27(200) |
| 3976.54(0) | 6.66(1) | 6.68(0) | 6.65(0) | 6.67(0) | Sm II .43(200) (Cr I .66(300)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 7.00(0) | | 6.76(0) | 6.86(1) | Tb II .86(250) Nd II .84(60) (Ho II .05(3)) |
| 3977.42(0) | 7.48(1) | | 7.36(0) | 7.22(0) | |
| 3977.77(0) | 7.85(1) | 7.77(0) | 7.82(1) | 7.90(1) | Fe I .74(300) |
| 3978.60(5) | 8.67(2) | 8.49(0) | 8.41(3) | 8.45(4) | Dy II .57(200) Ce II .65(125) |
| 3979.03(0) | | | 9.26(0) | 9.01(1) | Sm II .20(150) (La II .08(8)) |
| 3979.42(4) | 9.53(6) | 9.49(4) | 9.53(2) | 9.41(2) | Cr II .52(20) Nd II .48(60) (Dy II .48(25)) |
| | | | | 9.62(1) | Eu II .63(8) |
| 3980.16(0n) | 0.15(1) | | 0.09(0) | 0.19(1) | (Tb II .28(3)) (S II .86(35)) |
| | 0.56(1) | | 0.64(1n) | 0.65(2) | |
| 3980.87(2) | 0.86(2n) | 0.75(0) | 0.83(1n) | 0.04(2) | Ce II .90(100) (Tb II .15(20)) |
| 3981.24(0) | 1.42(1) | 1.38(0) | | 1.44(0) | Nd II .22(15) La II .36(10) |
| 3981.62(1) | 1.74(0) | | | | Fe I .77(150) (Fe II .61(pr)) (Ti I .76(100)) |
| 3981.98(3) | 2.12(2) | 1.82(1) | 1.85(1n) | 1.82(3) | Dy II .94(100) Pr II .06(150) Tb II .92(150) Ti II .01(3) (Zr II .01(3)) |
| | | 2.05(0) | 2.11(1) | 2.17(2) | |
| 3982.29(1) | 2.37(1) | 2.43(0) | 2.42(0) | 2.43(1) | Nd II .36(20) Pr II .50(40) |
| 3983.00(1n) | 3.06(1) | 2.93(1n) | 2.92(2) | 3.00(4) | Gd II .01(80) Ce II .90(60) Sm II .14(200) |
| | 3.41(1) | 3.55(0) | 3.50(0) | 3.54(2) | Nd II .40(10) |
| 3983.70(2) | 3.74(3) | | | | Dy II .66(150) (Tb II .85(15)) (Tb II .04(15)) |
| 3984.17(3n) | 4.02(2n) | 3.94(2) | 3.96(4) | 4.05(7) | Fe I .96(200) Dy II .23(80) (Cr I .91(200)) |
| | 4.37(1) | 4.15(0) | 4.30(1) | | Dy II .23(80) |
| 3984.75(1) | 4.74(2) | 4.68(1n) | 4.57(1) | 4.67(2) | Ce II .68(100) (Dy II .70(2)) (Tb II .84(6)) (Zr II .76(4)) |
| 3985.28(1) | 5.27(1) | 5.00(0) | | 5.06(0) | Tb II .08(5) |
| 3985.46(0) | | 5.42(0) | 5.53(0) | 5.54(0) | Fe I .39(125) |
| 3985.94(1n) | 6.04(2) | 6.03(2n) | 6.08(1) | 6.00(1) | Fe I .17(125) Mn II .01(1) (Ho II .80(6)) |
| 3986.35(0) | 6.51(1) | 6.54(0) | 6.49(1) | 6.50(2n) | Nd II .23(40) Tb II .34(15) (Ho II .5(5)) |
| 3986.73(1) | 6.74(0) | | | | Mg I .73(15) Sm II .68(150) |
| 3987.18(1) | 7.21(1) | | 7.11(0) | 7.02(1) | Gd II .21(600) (Dy II .06(3)) |
| 3987.70(1) | 7.73(1) | 7.78(0) | 7.58(4) | 7.63(2) | Nd II .81(5) Ho II .55(3) |
| 3988.26(1) | 8.30(0) | | | 8.09(1) | Eu II .24(8) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 3988.65(0) | | | | 8.52(0) | La II .52(500) |
| | 9.02(0) | | 9.05(0) | 8.94(0) | (Nd II .81(8)) |
| 3989.35(0) | 9.42(0) | 9.48(0) | 9.55(0n) | 9.24(1) | Gd II .25(50) Ce II .44(30) |
| 3989.77(1) | 9.82(1) | | | 9.78(0) | Pr II .72(100) Ti I .76(150) |
| 3990.25(1) | 0.25(2) | 0.22(1n) | 0.20(1) | 0.41(0) | Fe I .38(70) Nd II .10(60) (Dy II .35(2)) (Ho II .35(1)) |
| 3990.93(1) | 1.04(1) | 1.04(1) | 0.89(1) | 0.74(1) | Zr II .14(40) Cr I .12(200) (S II .94(40)) |
| 3991.39(1n) | 1.45(1) | | 1.15(3) | 1.22(3) | Dy II .33(40) |
| 3991.86(0n) | 1.84(0) | 1.70(1) | 1.71(1n) | 1.80(2) | Si II .77(2n) Nd II .74(80) Gd II .69(15) Pr II .89(25) Dy II .89(2) (Ho II .85(1)) |
| 3992.34(0n) | 2.31(0n) | 2.26(0) | 2.30(0n) | 2.37(1n) | Ce II .39(125) (Pr II .18(10)) (Tb II .20(2)) |
| 3992.79(1) | 2.85(1) | 2.90(0) | 3.04(1) | 2.95(0) | Ce II .91(15) (Nd II .57(15)) |
| 3993.24(0) | 3.31(0) | | | 3.18(0) | Gd II .21 (200) Sm II .31(200) (S II .53(50)) |
| 3993.74(1) | 3.80(1) | 3.87(1n) | 3.81(1n) | 3.84(1n) | Ce II .82(200) (Mn II .86(1)) (Eu II .93(15)) |
| 3994.19(0) | 4.29(1) | 4.48(0) | 4.37(0) | 4.31(0) | Gd II .16(800) (La II .50(10)) |
| 3994.84(1) | 4.81(1) | | 4.79(1) | 4.83(2) | Pr II .83(200) (N II .00(300)) (Nd II .68(80)) |
| 3995.38(1) | 5.31(1n) | 5.28(1) | 5.42(0) | 5.31(1) | Nd II .24(15) Co I .31(1000) |
| 3995.82(0) | 5.90(0) | | 5.84(1) | 5.90(0) | La II .75(400) Al II .86(30) Fe I .99(60) Eu II .98(10) Tb II .80(6) |
| 3996.40(1) | 6.38(1) | 6.27(0) | 6.32(2) | 6.43(2) | Gd II .32(800) (Fe II .36(pr)) |
| | | | 6.56(2) | | Dy II .70(150) Tm II .52(200) (Tb II .68(2)) |
| 3996.79(1) | 6.82(2) | | 6.95(1) | 6.91(0) | |
| | 7.18(1) | | | | V II .13(200) Pr II .05(40) |
| 3997.39(0) | 7.53(0) | 7.52(0) | 7.53(0) | | Fe I .40(300) Nd II .44(10) |
| 3997.88(1) | 8.00(1) | | 7.77(1n) | 7.81(2n) | Gd II .76(300) Si II .00(1n) Fe I .06(150) (Pr II .96(6)) (Dy II .10(2)) |
| 3998.53(0n) | 8.54(0) | | | 8.40(0) | Ti I .64(150) Tb II .41(15) |
| | 8.96(1) | 8.93(1n) | 8.93(1n) | 9.02(2n) | Zr II .98(30) (Eu II .81(4)) (S II .79(60)) |
| 3999.11(3n) | 9.30(1) | 9.26(1) | | 9.30(1n) | Ce II .24(500) Pr II .19(20) Tb II .41(25) |
| 3999.93(1n) | 9.99(1) | 0.01(0) | 9.73(0) | 9.84(1) | Mn II .06(1) Tb II .01(10) Pr II .19(40) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4000.48(2) | 0.60(1) | | 0.29(3) | 0.36(5) | Dy II .45(800) (Pr II .48(15)) (Nd II .49(30)) (Nd II .56(20)) |
| 4000.67(0) | 0.80(0) | 0.77(0) | 0.89(0) | | |
| | | | 1.19(1) | 1.18(2) | Gd II .26(600) (Ce II .05(4)) |
| 4001.37(1) | 1.42(1) | 1.36(1) | 1.47(1) | 1.52(1) | (Cr I .44(200)) |
| 4001.68(0) | | | 1.74(0) | | Fe I .67(80) |
| 4001.99(2) | 2.05(1) | 2.01(1) | 2.10(2) | 2.09(2) | Fe II .07(2) Gd II .96(25) (Tb II .20(50)) |
| 4002.45(3) | 2.55(4) | 2.52(2) | 2.56(4) | 2.64(2) | Fe II .55(3) Cr II .48(5) (Tb II .60(100)) |
| 4002.82(1) | 2.93(1) | 2.78(0) | 2.83(0) | 3.04(1) | V II .94(80) (Ho II .70(3)) (Zr II .95(2)) |
| 4003.17(3) | 3.28(3) | 3.26(2) | 3.32(2) | 3.38(1) | Cr II .33(25) |
| 4003.76(1) | 3.86(1) | 3.88(1n) | 3.75(1) | 3.83(1) | Ce II .77(100) Gd II .85(30) Fe (II?) .77(80) (Ti I .81(50)) (Eu II .71(12)) (Tb II .78(15)) (Tb II .91(10)) |
| 4004.01(1) | 4.27(0) | | 4.17(1) | 4.23(1) | Nd II .01(60) Fe II .15(pr) |
| 4004.44(0) | | | | | Eu II .59(6) Tb II .52(8) |
| | 4.72(1) | 4.75(0) | 4.82(1) | 4.83(2) | Gd II .94(150) (Pr II .71(25)) |
| 4005.08(3) | 5.13(2n) | 5.19(1n) | 5.29(1) | 5.38(1) | Fe I .25(250) |
| 4005.61(1) | 5.78(1) | 5.83(0) | 5.69(1) | 5.75(1) | V II .71(800) Tb II .55(200) |
| 4006.14(0) | | | | 6.12(0) | |
| 4006.29(0) | 6.30(1) | | 6.31(0) | 6.38(0) | Fe I .32(60) |
| 4006.84(1n) | 6.79(1) | 6.54(0) | 6.67(0) | 6.76(1) | Cr II .75(1) Pr II .70(8) |
| | 7.23(0) | 7.00(0) | | 7.10(0) | Fe I .27(80) |
| 4007.46(1) | 7.54(0) | 7.53(0) | 7.29(0) | 7.37(0) | Cr II .56(2) Nd II .44(50) Ce II .59(15) |
| | | 7.78(0) | 7.68(1) | 7.73(1) | Fe II .72(pr) (S II .78(5)) (Dy II .77(3)) (La II .64(7)) |
| 4007.96(1) | 8.02(1) | | 8.09(1) | 8.04(1n) | (Er (II?) .97(S7)) |
| | | 8.50(1) | | 8.53(1) | |
| 4008.68(2) | 8.86(2) | | 8.74(1n) | 8.85(2n) | Gd II .91(400) Eu II .87(6) Pr II .71(75) |
| 4009.28(2) | 9.32(1) | 9.23(0) | | 9.19(1) | Gd II .22(80) (He I .27(10)) |
| | | | 9.54(1) | 9.60(1) | Tb II .54(12) |
| 4009.77(1) | 9.76(1) | 9.68(1) | | 9.76(1n) | Fe I .72(120) |
| 4010.15(1) | 0.18(1) | | | 9.94(2) | Dy II .08(3) |
| | | 0.37(1) | 0.49(1) | 0.41(0) | Nd II .45(10) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4010.62(1) | 0.62(1) | 0.71(1) | 0.66(0n) | | Mn II .84(1) (Pr II .64(12)) |
| 4011.18(1n) | 1.39(2n) | 1.34(1) | 1.19(1) | 1.17(2) | Dy II .30(30) Nd II .07(15) |
| 4011.87(0) | 1.75(1) | 1.45(1n) | 1.58(2) | 1.64(2) | Eu II .69(100) |
| | | 2.32(2) | 2.24(0) | 2.26(3) | Ti II .39 (50) Nd II .25(300) Ce II .39(300) |
| 4012.37(9) | 2.50(9) | 2.55(5) | 2.56(7n) | 2.58(6) | Cr II .47(30) Ce II .39(300) Fe II .47(1) (Tb II .46(4)) |
| 4012.82(2n) | 2.89(1) | | | 2.84(1) | Eu II .82(15) Nd II .70(50) Tb II .84(40) |
| 4013.02(0) | | | 3.21(0) | 3.23(0) | Nd II .22(15) |
| 4013.50(0) | 3.53(1) | 3.50(1n) | | | |
| 4013.75(1) | 3.86(1) | | 3.67(1n) | 3.68(2) | Ga II .80(250) Fe I .82(200) Gd II .95(60) Fe I .80(80) (A II .87(200)) |
| 4014.39(1) | | 4.26(0) | 4.26(0) | | Ho II .18(2) |
| 4014.43(1) | 4.54(1) | | 4.54(0) | 4.45(1) | Fe I .53(200) (Dy II .71(40)) |
| 4014.85(1) | 4.98(1) | 4.75(0) | | 4.70(0) | Ce II .90(125) Dy II .71(40) |
| | | | | 5.11(1) | Dy II .18(4) |
| 4015.50(1n) | 5.51(1) | | 5.34(1) | 5.46(2) | Ni II .50(1) Pr II .39(40) Tb II .52(15) |
| | 5.87(0) | 5.83(0n) | 5.88(1) | 6.00(1) | Ce II .88(20) Tb II .94(8) (Tb II .04(2)) |
| 4016.24(1n) | 6.32(1n) | | 6.42(1) | 6.48(1) | Tb II .34(12) |
| 4016.81(0) | 6.86(1) | 6.75(0) | 6.86(0) | 6.84(1) | Pr II .75(20) |
| 4017.05(1) | | 7.34(1) | | 7.27(1) | Fe I .15(80) |
| 4017.51(1) | 7.57(1) | | 7.49(1) | 7.63(1) | Eu II .58(100) Eu II .72(20) (Ce II .60(10)) |
| 4017.83(2) | 7.97(2) | 7.95(1) | 7.99(1) | 8.12(1) | Cr II .96(3) (Tb II .85(4)) |
| 4018.44(1n) | 8.34(1) | 8.18(0) | 8.33(2) | 8.40(2n) | Zr II .38(10) Eu II .39(6) |
| 4018.94(0) | 8.67(1) | | | | Nd II .83(30) |
| | 9.10(1) | 9.04(0) | 9.07(1n) | 9.14(2) | Tb II .14(20) |
| 4019.36(1n) | 9.59(1) | | | 9.60(0) | Dy II .48(2) |
| 4020.06(0) | 9.96(1) | 9.96(2) | 9.87(1n) | 9.97(1) | Sm II .98(80) Nd II .81(12) (Nd II .06(5)) |
| 4020.60(0) | | | 0.30(0) | 0.43(0) | Tb II .47(30) (Sc I .40(50)) |
| 4020.88(2) | 0.92(2n) | 0.88(1) | 0.86(2n) | 0.90(3n) | Nd II .87(60) Co I .90(500) Dy II .90(4) Pr II .99(15) |
| 4021.38(1) | 1.36(0) | | 1.26(0) | 1.36(0) | Nd II .33(80) |
| 4021.83(1) | 1.91(1) | | 1.68(1) | 1.78(2) | Fe I .87(200) Ti I .83(100) Nd II .80(60) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| | | | | 2.29(1) | Gd II .33(300) |
| 4022.30(3) | 2.42(3) | 2.24(2n) | 2.33(2) | 2.40(2n) | Cr II .36(3) Gd II .33(300) (Pr II .20(8)) |
| 4022.60(0) | 2.74(1) | | | 2.85(1) | Pr II .74(15) (Ho II .86(2)) |
| 4022.95(1) | 3.07(1) | 3.01(0) | 3.00(1) | 3.07(2) | Nd II .00(80) Sm II .23(300) |
| 4023.30(2) | 3.36(1) | | 3.44(1) | 3.56(1) | V II .39(600) La II .58(40) |
| 4023.84(2n) | 3.95(2) | 3.77(1) | 3.80(3) | 3.87(3) | Sc I .69(100) Tb II .10(30) |
| | | | 4.34(0) | 4.36(2) | Ce II .49(60) Dy II .44(12) (Eu II .24(4)) |
| 4024.48(5) | 4.54(5) | 4.49(3) | 4.53(4n) | 4.60(3) | Fe II .55(5) (Zr II .45(12)) (Nd II .78(30)) |
| 4025.06(1n) | 5.23(1) | | 5.04(2) | 5.09(2) | Ti II .14(25) (F II .01(150)) |
| 4025.56(1n) | 5.66(2) | 5.50(2n) | 5.56(2n) | 5.57(2) | Pr II .55(20) F II .50(300) Tb II .74(10) Dy II .75(3) |
| 4025.81(0) | | | | | La II .87(50) |
| 4026.21(0) | 6.26(0) | | | 6.21(1) | He I .19(70) |
| 4026.52(1n) | 6.59(1) | 6.48(1) | 6.59(1) | 6.58(1n) | Al II .50(30) |
| 4027.00(0) | 7.13(1) | | 7.00(1) | 7.08(1n) | Pr II .84(15) |
| 4027.42(0) | 7.60(0) | 7.57(1n) | | | |
| 4027.88(3) | 7.80(1) | | 7.66(3) | 7.74(4) | Dy II .79(30) |
| 4028.39(3) | 8.46(2) | 8.38(1n) | 8.27(3n) | 8.35(3n) | Ti II .34(80) Ce II .41(150) (Dy II .32(8)) |
| 4028.77(1) | 8.72(0) | | 8.70(1) | 8.81(1) | S II .79(200) |
| | 9.40(0) | | 9.22(1) | 9.29(1n) | |
| 4029.61(3n) | 9.74(2) | 9.47(1) | 9.61(3) | 9.71(3n) | Fe I .64(80) Zr II .68(20) (Eu II .58(4)) |
| 4030.26(3) | 0.32(3n) | 0.30(2) | 0.38(3) | 0.46(2) | Fe I .49(120) Nd II .47(25) |
| 4030.88(1) | 1.00(1) | 0.87(0) | 0.80(1) | 1.09(1) | Cr II .68(3) Mn I .76(500) (Cr II .13(2)) |
| 4031.38(3) | 1.45(2) | 1.43(1) | 1.47(1n) | 1.52(2n) | Fe II .46(1) Ce II .34(150) (Eu II .35(4)) (Nd II .54(10)) |
| 4031.82(1) | 1.87(1) | | 1.84(0) | 1.99(0) | Nd II .81(100) Fe I .96(80) Pr II .76 (50) (Tb II .65(50)) (La II .68(300)) |
| 4032.46(1) | 2.39(1) | 2.30(1n) | 2.37(2) | 2.45(3) | Dy II .48(50) (Pr II .49(15)) |
| 4033.03(3) | 2.96(4) | 2.92(4) | 2.95(4) | 3.04(4) | Fe II .95(3) Mn I .07(400) Tb II .05 (200) Gd II .08(8) Pr II .97(15) |
| 4033.22(1) | | | | | Gd II .08(8) |
| 4033.77(2) | 3.80(1n) | 3.58(1) | 3.53(1) | 3.58(3) | Pr II .86(75) Dy II .67(10) (P II .68(15)) |
| 4034.20(3) | 4.25(2) | 4.09(1n) | 4.14(2n) | 4.09(3n) | (Eu II .10(4)) (Nd II .01(4)) (Zr II .10(5)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4034.55(1) | | 4.38(1) | | 4.29(2n) | Mn I .49(250) |
| | 4.74(0) | 4.84(0) | 4.90(1) | 4.87(1) | |
| 4035.06(1n) | 5.10(0) | | | | Sm II .11(250) Cr II .15(1) |
| 4035.45(1n) | 5.50(1n) | 5.42(0n) | 5.52(0) | 5.40(1) | (Fe II .54(pr)) (A II .47(30)) |
| 4035.80(0) | | | | 5.77(0) | V II .63(400) |
| 4036.30(4n) | 6.35(2n) | 6.19(1) | 6.16(1n) | 6.19(4n) | Dy II .34(15) Tb II .45(6) (P II .22(15)) (Nd II .00(4)) |
| 4036.97(1) | 7.06(1) | 7.09(1) | | 6.80(0) | (V II .78(60)) |
| 4037.41(3) | 7.37(1) | | 7.19(3) | 7.29(4) | Gd II .33(1500) (Eu II .15(5)) |
| | | | | 7.75(1) | Ce II .66(25) |
| 4037.92(4) | 7.99(5) | 7.97(3) | 8.01(3) | 7.99(2) | Cr II .03(25) Gd II .90(1200) (Nd II .12(20)) (Pr II .15(20)) |
| 4038.47(1) | 8.60(0) | 8.66(0) | 8.38(1) | 8.41(1) | Dy II .53(8) Pr II .47(40) |
| 4038.93(1) | | | 8.76(0) | 8.80(1) | |
| 4039.28(0) | 9.26(0) | 9.33(0n) | 9.16(1) | 9.12(1) | Pr II .36(30) (Tb II .20(3)) |
| 4039.61(1) | | | | 9.44(3) | Gd II .67(100) Gd II .49(50) (V II .57(20)) |
| 4040.04(0) | | | 0.02(2n) | 0.12(2) | |
| 4040.33(1) | | | | | (Zr II .24(4)) |
| 4040.83(1) | 0.84(1) | 0.65(1) | 0.72(3) | 0.82(3) | Ce II .76(300) Nd II .80(100) |
| 4041.45(1) | | | 1.24(2) | 1.37(3) | Mn I .36(100) |
| | 1.64(0) | | 1.76(2) | 1.85(2) | Sm II .68(200) |
| 4042.05(1) | | | 2.08(0) | | Eu II .02(15) Dy II .99(10) (Ce II .14(8)) |
| | | 2.44(0) | | 2.33(1) | Tb II .36(6) |
| 4042.57(1) | 2.79(1) | | 2.62(2) | 2.78(2) | Ce II .58(200) Sm II .90(250) Sm II .72(200) La II .91(300) Gd II .76(20) |
| 4043.10(0) | | 3.41(0) | 3.35(0) | 3.25(1) | |
| 4043.49(1) | | | | 3.62(1) | Nd II .60(15) (Cu II .50(75)) |
| 4043.90(2) | 3.98(1) | 3.93(1) | 4.03(2) | 4.07(2n) | Fe II .01(2) |
| 4044.26(0) | | 4.40(0) | | 4.51(1) | Fe I .61(70) P II .49(150) (K I .14 (800)) (Nd II .35(5)) (A I .42(1200)) |
| 4044.74(1) | 5.02(0) | 4.65(1) | 4.78(1) | 4.90(2) | Pr II .82(60) |
| 4045.23(2) | | 5.26(0) | 5.37(0) | 5.41(2) | Ho II .43(200) Gd II .15(100) |
| 4045.67(6) | 5.71(4) | 5.77(4) | 5.84(3) | 5.88(3) | Fe I .82(400) (A I .97(150)) |
| 4046.42(3n) | 6.47(2n) | 6.32(2) | 6.38(3) | 6.42(5) | Ce II .34(100) |
| | | 6.68(1) | | 6.71(0) | Pr II .64(8) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4046.80(2n) | 6.87(2n) | 6.94(1) | 6.91(1) | 6.94(2) | Gd II .84(150) (Fe II .81(pr)) (Pr II .10(15)) |
| 4047.27(0n) | 7.26(1) | | | | Sm II .16(80) K I .20(400) |
| 4047.92(2) | 7.91(1) | 7.84(0n) | 7.68(1) | 7.75(1n) | Gd II .81(100) |
| | | | 8.09(1) | 8.23(2) | (Cr II .02(pr)) (Er (II?) .35(S1)) |
| 4048.46(1) | | | 8.50(1) | | Gd II .60(90) |
| 4048.74(3) | 8.65(3n) | 8.76(1) | 8.84(1) | 8.65(2) | Fe II .83(3) Gd II .60(90) (Zr II .68(25)) (Nd II .81(15)) |
| 4049.00(3) | 9.03(4n) | 9.06(2n) | 9.25(2) | 8.94(2) | Cr II .16(18) |
| 4049.53(1n) | 9.42(1) | | 9.36(1) | 9.35(2) | Gd II .43(1200) |
| | | 9.67(1) | | 9.70(1) | |
| 4049.90(1n) | 9.84(1) | 9.83(0) | 9.77(2) | 9.89(2) | Gd II .86(2000) (La II .08(200)) |
| | 0.34(1) | 0.35(1) | 0.22(1) | | Zr II .32(15) |
| 4050.54(3) | 0.59(2) | | 0.42(2) | 0.45(4) | Dy II .58(100) (Eu II .43(4)) |
| | 0.99(0) | | 0.91(1n) | 0.94(1) | |
| 4051.14(2) | 1.24(1) | 1.19(1n) | 1.26(2n) | 1.32(1) | Nd II .14(60) Pr II .15(20) (Fe II .21(pr)) |
| | 1.51(1) | 1.69(1) | 1.59(1) | 1.72(0) | (Tb II .52(4)) |
| 4051.84(3) | 1.89(4) | 1.93(3) | 2.00(4) | 2.08(3) | Cr II .97(12) (Tb II .87(30)) |
| 4052.40(1) | 2.46(1) | 2.39(1) | | 2.36(1) | (Tb II .43(4)) |
| | | 2.50(0) | 2.54(1n) | 2.67(2) | Pr II .58(10) |
| 4052.94(1) | 2.92(1) | | | | (Tb II .87(20)) (A II .94(20)) |
| 4053.37(4) | 3.43(4) | 3.32(1) | 3.20(3) | 3.28(4) | Gd II .29(1000) Cr II .45(1) |
| | | | 3.48(1) | 3.57(0) | Cr II .45(1) Ce II .51(100) |
| 4053.84(0) | 3.83(3) | 3.98(7) | 3.85(2) | 3.95(4) | Ti II .84(8) |
| 4054.01(3) | 4.06(6) | 4.03(3n) | 4.16(2) | 4.21(1) | Cr II .18(8) |
| 4054.73(1) | 4.53(1) | 4.68(1) | 4.64(0) | 4.62(1) | |
| 4054.90(1) | 4.84(1n) | 4.81(1) | 4.86(2n) | 5.01(3) | Ce II .99(50) Pr II .84(80) (Fe I .88(25)) (Nd II .86(10)) |
| 4055.23(1) | 5.27(1n) | 5.35(1) | 5.22(0n) | 5.34(1) | Dy II .16(40) Fe I .04(40) (Er (II?) .47(S2)) |
| 4055.60(1) | | | 5.62(1n) | 5.77(1) | |
| 4056.00(2) | 6.07(2n) | 6.03(1) | 6.13(2) | 6.22(1) | Cr II .05(4) Gd II .01(30) (Ti II .21(2)) |
| 4056.55(1) | 6.56(1n) | 6.49(1) | 6.53(2) | 6.63(2) | Pr II .54(80) |
| 4056.99(1) | 6.99(1) | 6.84(1) | 7.08(1) | 7.10(1) | (Nd II .84(4)) (Tb II .06(4)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4057.44(3) | 7.45(4) | 7.40(2n) | 7.48(3) | 7.51(3) | Fe II .46(2) Dy II .40(2) (Mg I .63(10)) |
| 4058.01(0) | 7.78(0) | | | | La II .08(5) Pb I .82(2000) |
| 4058.37(2n) | 8.33(2n) | 8.30(1n) | 8.35(1n) | 8.26(2n) | Fe I .23(80) |
| 4058.66(0n) | 8.81(1n) | 8.70(0) | 8.71(1n) | 8.92(0) | Fe I .76(40) (Pr II .78(15)) (Cr I .77(80)) |
| 4059.41(1) | 9.41(1) | | 9.23(1) | 9.26(1) | Gd II .37(80) Eu II .37(15) (Tb II .47(4)) |
| 4059.86(1) | 9.81(1) | 9.73(1) | 9.60(1) | 9.70(2) | Nd II .96(50) (Er (II?) .78(82)) |
| 4060.27(0) | 0.32(0) | | 0.06(1) | 0.09(0) | Ti I .26(60) |
| 4060.67(2) | 0.69(1) | 0.67(0) | 0.42(0) | 0.49(1) | Dy II .58(4) (Tb II .86(40)) |
| 4061.09(1) | | | 1.07(1) | | Nd II .08(200) |
| 4061.32(0) | 1.21(1) | | | 1.19(1n) | Gd II .30(80) |
| 4061.71(6) | 1.76(5) | 1.59(2) | 1.69(3n) | 1.67(3n) | Fe II .79(1) Eu II .57(10) (Cr II .77(pr)) |
| 4062.26(1) | | 2.24(0) | 2.24(0) | | Eu II .15(15) Ce II .22(60) (Pr II .22(8)) |
| 4062.52(0) | 2.36(1) | | 2.46(1) | 2.42(2n) | Fe I .44(120) |
| | | 2.60(1) | | | Gd II .59(500) Eu II .65(15) |
| 4062.77(3) | 2.83(2) | 2.75(1n) | 2.82(1) | 2.94(1) | Pr II .82(125) (Tb II .80(10)) |
| | | | 3.36(2) | 3.44(4) | Gd II .39(1500) |
| 4063.50(6) | 3.54(5) | 3.52(3) | 3.66(3) | 3.70(2) | Fe I .60(400) Gd II .59(200) (Mn I .53(100)) |
| 4063.99(0) | 4.08(1) | 4.06(1) | 4.06(1) | | Cr II .14(1) Tb II .95(15) (Cr II .94(pr)) |
| | | 4.23(1) | 4.25(1) | 4.25(1) | |
| 4064.32(1) | 4.32(1) | | 4.44(1) | 4.42(2n) | Ti II .40(2) |
| 4064.70(0) | 4.74(0) | 4.57(1) | 4.75(0) | 4.87(2) | Sm II .58(300) (P II .64(30)) |
| 4065.15(2) | 5.10(1n) | 4.99(1) | 5.00(1) | 5.13(1n) | Ho II .10(10) V II .07(100) (Ti I .10(80)) |
| 4065.75(1) | | 5.73(0) | 5.85(0) | 5.60(0) | Gd II .61(15) Cr I .72(80) |
| 4066.11(0) | 6.02(0n) | 6.06(0) | 5.91(1) | 6.03(1n) | Eu II .05(4) (Cr II .16(pr)) |
| 4066.49(0) | 6.65(0) | 6.57(0) | 6.50(0) | 6.57(1) | Sm II .74(200) Gd II .56(5) |
| 4066.88(0) | 6.92(1n) | | | | Fe I .98(100) Ni II .05(30) (Cr II .05(pr)) (Ho II .04(2)) |
| 4067.35(0) | 7.26(0) | 7.15(1) | 7.20(1) | 7.23(1n) | Ce II .28(50) Fe I .28(80) La II .39(100) |
| 4068.01(0) | 7.94(1) | | 7.88(1) | 7.90(1) | Fe I .98(150) (Ho II .80(2)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 8.14(1) | 8.15(0) | 8.22(0) | 8.25(1) | |
| 4068.44(1) | 8.52(0) | | 8.39(1) | 8.50(0) | Sm II .33(100) (Eu II .34(4)) |
| 4068.88(0) | 9.01(0) | 8.99(0n) | 8.78(0) | 8.86(1) | Ce II .84(75) Nd II .90(10) (Pr II .80(15)) |
| | 9.21(0) | 9.18(0) | 9.22(0) | 9.40(1) | Nd II .27(80) (Tb II .30(1)) |
| 4069.79(1n) | 9.86(2n) | 9.92(2) | 9.98(1n) | 9.95(1n) | Fe II .88(1) Ce II .09(15) |
| 4070.16(0) | 0.28(0) | | 0.22(1n) | 0.09(2) | Gd II .29(600) (Pr II .26(10)) |
| | | | 0.43(1) | 0.40(2n) | Gd II .39(200) (Tb II .58(10)) |
| 4070.68(4n) | 0.81(4) | 0.84(3) | 0.92(3) | 0.99(2) | Cr II .90(10) (Tb II .58(10)) |
| 4071.08(0) | 1.18(0) | | | | Zr II .09(4) |
| | | 1.34(0) | 1.38(0) | 1.32(0) | Eu II .38(10) |
| 4071.65(2) | 1.73(4) | 1.72(3n) | 1.79(3) | 1.82(4) | Fe I .74(300) Ce II .81(150) |
| 4072.11(0) | 2.28(1) | | 2.12(1) | 2.14(0) | O II .16(300) (P II .13(30)) |
| 4072.48(5) | 2.62(5) | 2.61(4) | 2.60(2n) | 2.60(4) | Cr II .56(4) (Tb II .35(4)) |
| 4072.68(0) | | | | | Dy II .65(3) |
| 4073.24(3) | 3.28(2) | 3.32(1) | 3.03(4) | 3.12(5) | Gd II .20(400) Dy II .11(150) |
| 4073.43(0) | | | | | Ce II .48(200) Fe II .45(8) |
| | | 3.63(1) | 3.55(3) | 3.59(3) | Gd II .76(1500) Fe II .45(8) |
| 4073.72(1) | 3.79(1) | 3.72(1) | 3.74(2) | 3.88(3) | Fe I .78(80) |
| 4074.18(0) | 4.14(1) | | | 4.27(1) | Dy II .02(3) |
| | 4.48(1) | 4.36(0) | | 4.47(1) | Fe II .41(2?) Nd II .42(8) (Eu II .48(3)) |
| 4074.72(1n) | 4.79(1) | 4.78(1n) | 4.67(0) | 4.84(1) | Fe I .79(80) |
| | | | | 5.07(3n) | Nd II .12(60) Nd II .27(50) (Tb II .22(20)) |
| 4075.41(4) | 5.48(6) | 5.48(4n) | 5.37(1n) | 5.28(2n) | Si II .45(2) (Gd II .47(15)) |
| 4075.83(2) | 5.97(2) | 6.02(1) | 5.61(4n) | 5.72(3n) | Cr II .97(4) Ce II .71(150) Sm II .84(250) Ce II .85(125) (O II .87(800)) (Tb II .90(2)) (Cr II .63(pr)) |
| 4076.24(1) | 6.37(1) | | 6.21(1) | 6.14(1) | |
| 4076.74(4) | 6.80(9) | 6.78(5) | 6.84(5) | 6.85(6n) | Cr II .87(3) Si II .78(1) (Fe I .64(60)) (La II .71(40)) |
| 4077.00(0) | | | | | Eu II .95(4) Fe II .16(3?) (Zr II .05(3)) |
| 4077.41(1) | | | 7.53(2) | 7.63(3) | Cr II .50(4) |
| 4077.61(3) | 7.63(8n) | 7.63(5) | 7.77(6) | 7.86(8) | Sr II .71(500) (Ce II .47(75)) (Cr II .50(4)) (La II .35(300)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4077.97(2n) | 8.05(2) | 7.86(5) | | | Dy II .97(800) (Er (II?) .97(S18)) |
| 4078.56(2) | 8.40(1) | 8.35(2) | 8.38(3) | 8.40(4) | Gd II .44(1200) Ce II .32(60) (Fe I .36(80)) (Ti I .47(125)) |
| 4079.17(1) | 8.94(0) | 9.05(0) | 9.01(1n) | 8.97(1) | |
| | 9.31(1) | | | 9.35(1) | |
| 4079.78(1) | 9.73(0) | 9.66(0) | 9.75(1n) | 9.85(3) | Fe I .84(80) Pr II .79(30) |
| 4080.19(0) | 0.25(0) | 0.27(0) | | | Nd II .23(50) (Fe I .22(60)) |
| 4080.53(0) | 0.65(1) | 0.35(1) | 0.40(1) | 0.48(1) | Ce II .44 (5) |
| 4081.22(1) | 1.35(1) | 1.08(1) | 1.12(1) | 1.13(1) | Ce II .22(150) Cr II .21(1) Pr II .02(50) (Eu II .04(5)) |
| 4081.82(0) | 1.72(0) | 1.68(1) | 1.85(1) | 1.85(1) | (Pr II .90(50)) |
| 4082.14(1) | 2.24(4) | 2.30(2) | 2.36(2) | 2.43(1) | Cr II .30(10) (Tb II .23(4)) |
| 4082.63(0) | 2.77(1) | 2.74(1) | 2.96(0) | 2.81(1) | Fe II .59(1) Sm II .60(100) (Nd II .58(3)) |
| 4083.09(0) | | 3.09(0) | | | |
| 4083.44(1) | 3.31(2) | 3.19(0) | 3.28(1) | 3.38(2) | Ce II .23(200) (Pr II .34(30)) |
| 4083.79(0) | 3.63(2) | 3.60(1) | 3.66(1) | 3.78(1) | Sm II .58(100) (Mn II .67(pr)) |
| | 4.10(0) | | | 4.17(0) | (Gd II .95(3)) |
| 4084.68(2n) | 4.65(2n) | 4.55(1) | 4.56(2) | 4.64(4) | Fe I .50(120) (Gd II .68(30)) |
| 4085.17(1) | | | | | Eu II .04(4) |
| 4085.46(0) | 5.38(1) | 5.32(1) | 5.30(2n) | 5.40(3) | Eu II .38(40) Ce II .23(100) Fe I .32(100) |
| 4085.62(1) | 5.66(1) | 5.66(1) | 5.59(2n) | 5.67(1) | Gd II .56(2000) Eu II .38(40) (Nd II .82(30)) (Zr II .68(5)) |
| 4086.04(3) | 6.09(3) | 6.15(2) | 6.18(2) | 6.14(1) | Cr II .14(8) Eu II .42(8) |
| 4086.61(0) | 6.63(1) | | 6.74(0) | | La II .72(300) |
| 4087.23(1n) | 7.33(2) | 7.18(1n) | 7.17(1) | 7.21(3n) | Dy II .21(25) Ce II .30(4) (Fe II .27(pr)) (Pr II .21(15)) |
| 4087.66(1) | 7.68(1) | 7.58(2n) | 7.62(2) | 7.68(4n) | Gd II .69(200) Cr II .63(2) (Nd II .47(4)) |
| 4087.92(0) | | | 8.06(0) | | |
| 4088.29(1) | 8.24(1) | 8.17(0) | 8.28(1) | 8.33(1) | |
| 4088.71(1) | 8.79(2) | 8.80(1) | 8.86(2) | 8.89(2n) | Cr II .90(1) Gd II .81(10) |
| 4089.36(1) | 9.55(1) | 9.56(1n) | 9.53(1) | | Cr II .49(2) (Tb II .34(15)) (Nd II .68(4)) (Tb II .50(6)) |
| 4089.79(0) | 9.80(1) | | 9.68(1) | 9.67(2) | Nd II .68(4) |
| 4090.39(1) | 0.45(1n) | 0.37(0) | 0.51(0n) | 0.39(1) | Zr II .52(10) |
| 4091.10(0) | 1.11(1) | 0.92(0) | | 1.01(1) | Ce II .95(6) (Nd II .99(3)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4091.78(3) | 1.72(1n) | | 1.52(0) | 1.59(3) | Dy II .53(20) Dy II .77(10) (P II .53(30)) |
| 4092.47(1) | 2.32(0) | | 2.08(0) | 2.31(1) | Sm II .27(400) |
| 4092.70(0) | 2.67(1) | | | 2.89(0) | |
| 4093.12(1) | 3.19(2) | 3.23(1) | 3.19(0) | 3.33(1) | Fe II .24(0) |
| 4093.89(0) | 3.96(0) | | | 3.98(0) | Ce II .96(30) |
| 4094.58(0) | 4.47(0) | | 4.56(0) | 4.64(0) | Gd II .48(300) (Nd II .62(5)) (Tb II .45(5)) |
| 4095.83(0) | | | 5.71(0) | 5.65(1) | Nd II .78(3) Fe I .98(80) |
| 4096.52(0) | | | 6.56(0) | 6.53(1) | (Pr II .34(12)) (Zr II .63(4)) |
| 4096.90(1) | | | | 7.18(1) | Eu II .80(40) Pr II .82(25) (Nd II .70(4)) |
| 4097.47(1) | 7.53(2) | 7.43(1) | 7.34(1) | 7.47(2) | Fe II .51(1) (Tb II .44(10)) |
| 4098.31(1) | 8.36(2) | 8.44(1) | 8.46(2) | 8.54(3) | Cr II .44(8) Gd II .61(3000) (Pr II .41(10)) |
| 4099.93(1) | 0.03(0) | 9.87(0) | | 9.81(2) | Mn II .00(1) (N I .94(150)) |
| 4100.66(0n) | | | | 0.64(1) | Fe I .74(80) Pr II .75(150) |
| 4101.77(xn) | 1.63(xn) | 1.72(xn) | 1.73(xn) | 1.69(xn) | $H_\delta$ .75 |
| 4102.27(1) | | | | | (Tb II .54(15)) |
| | | | 3.02(0) | 3.32(0) | Dy II .31(600) (Mn I .96(100)) (F II .08(150)) (Si I .95(12)) |
| 4104.18(0) | | 4.02(0) | | 4.20(0) | Fe I .13(100) (Nd II .23(10)) (Tb II .91(20)) |
| 4104.98(1) | 5.01(0) | | | | Mn II .01(2) Ce II .00(50) Dy II .05(8) (O II .00(7)) |
| 4105.65(0) | | | | | Gd II .79(15) Eu II .84(6) (Pr II .73(8)) |
| 4106.31(0n) | | | | | Ce II .13(30?) Dy II .39(3) (Nd II .58(8)) |
| | 6.53(0) | | | 6.65(0) | Dy II .70(2) (Nd II .58(8)) (Ho II .6(2)) |
| 4106.80(0n) | 6.98(0) | | | | Ce II .88(5d?) |
| 4107.40(1) | 7.48(1) | 7.30(0) | | 7.39(0) | Ce II .43(200) Fe I .49(120) Sm II .39(200) (Nd II .45(4)) (Dy II .45(2)) |
| | 7.85(0) | | 7.73(0) | | Eu II .90(10) Pr II .75(10) (Nd II .96(4)) |
| 4108.56(0) | 8.46(0) | 8.59(0) | | 8.42(1) | Gd II .40(50) |
| 4108.92(0n) | 9.18(1) | | | | Nd II .07(100) |
| 4109.48(0) | 9.53(1) | | | 9.48(1) | Sm II .40(150) Nd II .46(200) |
| 4110.07(0) | 9.99(0) | 9.72(0) | 9.97(0) | 9.95(0) | Fe I .81(120) N I .98(1000) (Eu II .93(4)) (Zr II .05(3)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4110.54(2) | 0.62(2) | 0.39(1n) | 0.44(2) | 0.49(4) | Ce II .38(60) Gd II .60(150) Gd II .43 (30) Nd II .47(40) (Co I .54(600)) |
| 4110.87(3) | 1.00(4) | 0.99(2) | 1.08(2) | 1.16(4) | Cr II .01(18) (Mn I .90(80)) (Eu II .07(5)) |
| 4111.39(2) | 1.48(3) | | | 1.51(1) | Gd II .44(500) Ce II .39(60) Dy II .35(125) |
| 4111.83(2) | 1.87(2) | 1.81(1n) | 1.86(2) | 1.95(3) | Gd II .74(100) Fe II .90(1) (Eu II .04(30)) (Eu II .17(20)) (Pr II .87(25)) |
| 4112.58(1) | 2.59(1n) | 2.62(1) | 2.64(1) | 2.50(1) | Cr II .59(1) |
| 4112.78(0) | 2.82(0) | 2.96(0) | | 3.00(1) | Fe I .97(70) |
| 4113.14(3) | 3.20(3) | 3.22(1) | 3.27(1) | 3.41(1) | Cr II .24(5) (La II .28(40)) |
| 4113.68(1) | 3.80(1) | 3.70(0) | 3.82(0n) | 3.91(2) | Gd II .77(15) Sm II .90(100) Ce II .73 (30?) Nd II .83(20) Pr II .89(25) |
| 4114.17(1) | 4.09(1) | | | | Dy II .09(1) (Tb II .15(20)) (N I .00(30)) |
| | 4.45(1) | | | 4.30(1) | Fe I .45(80) |
| 4114.78(2) | 4.85(1) | 4.63(0) | 4.67(2n) | 4.70(2) | |
| 4115.34(1) | 5.44(2) | 5.28(1) | 5.30(3) | 5.36(3) | Ce II .37(150) Gd II .38(80) (Tb II .34(20)) |
| | | 5.73(0) | 5.68(0) | | |
| 4116.09(0) | 6.06(1) | 6.05(0) | 6.13(1) | 6.02(1) | |
| 4116.36(0) | | | | 6.41(1) | (F II .55(50)) |
| | 6.68(0) | 6.87(1n) | 6.89(1n) | 6.77(1) | Cr II .66(2) Nd II .76(30) |
| 4117.28(1) | 7.04(1) | | 7.18(2n) | 7.12(3) | Ce II .01(75) (P II .09(50)) |
| | 7.33(1) | | | 7.40(0) | Ce II .29(20?) |
| 4117.52(0) | 7.67(1) | | | 7.68(0) | |
| 4118.10(0) | 8.11(1) | 8.29(0) | 8.04(1) | 8.10(0) | Ce II .14(200) |
| 4118.41(1) | 8.45(1) | 8.42(1) | 8.45(2) | 8.45(1) | Pr II .48(200) Sm II .55(400) Fe I .55(200) |
| 4118.74(0) | | 8.72(1) | 8.84(1) | 8.83(0) | Co I .77(1000) |
| 4118.98(3) | 9.07(2) | 8.93(0) | 8.92(0) | 8.97(1) | Ce II .02(25) |
| 4119.42(2) | 9.48(2) | | | 9.32(0) | Gd II .38(80) Dy II .32(20) (Fe II .53(pr)) (Eu II .30(15)) |
| 4119.84(2) | 9.76(2) | 9.66(1) | 9.73(1n) | 9.69(1) | Ce II .78(20) Ce II .88(20) |
| 4120.16(0) | 0.16(0) | 0.24(1) | | 0.01(1) | Fe I .21(80) |
| 4120.77(1n) | 0.66(1) | 0.70(0) | 0.85(1n) | 0.60(1) | Ce II .83(150) Nd II .65(6) (P II .78(2)) |
| 4121.04(1) | 1.01(1n) | 1.08(0n) | | 0.95(1) | Ce II .83(150) Gd II .03(8) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| | 1.29(0) | | | 1.31(1) | Co I .32(1000) |
| 4121.57(1) | 1.69(1) | | | | |
| 4121.93(1) | 1.93(1) | | 2.11(0) | 1.96(1) | Fe I .81(100) (Nd II .94(4)) |
| 4122.54(5) | 2.63(7) | 2.60(4) | 2.64(5) | 2.75(4) | Fe II .64(4) (Fe I .51(70)) |
| 4123.19(1) | 3.25(0) | 3.23(1) | 3.22(1n) | 3.31(3) | La II .23(400) Ce II .23(5?) |
| 4123.57(1) | 3.56(2) | | | | Ce II .49(20?) |
| 4123.79(1) | 3.79(1) | 3.80(1) | 3.82(1) | 3.89(2) | Ce II .87(150) Sm II .96(150) Fe I .75 (80) (Nd II .88(40)) (Tb II .80(5)) |
| 4124.24(0) | 4.28(0) | | | | |
| | | | 4.52(1n) | 4.56(2) | Eu II .54(10) |
| 4124.67(4) | 4.77(4) | 4.72(3) | 4.73(2n) | 4.80(2n) | Dy II .63(40) Fe II .79(1) Eu II .89(12) (Y II .91(18)) |
| 4125.27(0) | 5.48(0) | 5.46(0) | 5.38(0) | 5.30(1) | Tb II .25(15) |
| 4125.95(0n) | 5.88(1) | | | 5.78(1) | Mn II .86(1) Fe I .62(80) (Ce II .78(2?)) |
| | 6.21(1) | | 6.28(0n) | | Fe I .19(80) |
| 4126.64(1) | 6.54(1) | 6.35(1n) | | 6.43(2) | (Cr I .52(100)) |
| 4126.94(1) | 6.83(0) | 6.90(1) | | 6.82(1) | |
| 4127.32(1) | 7.08(2) | 7.24(1) | 7.13(1) | 7.18(2) | Cr II .08(3) Ce II .37(150) (Tb II .29(10)) |
| | 7.47(1) | 7.56(0) | | 7.49(2) | Fe I .61(100) Gd II .72(25) (Ce II .37(150)) (P II .49(70)) |
| 4128.04(x) | 8.05(x) | 8.03(9) | 8.06(8) | 8.06(x) | Si II .05(8) |
| | 8.38(0) | | | 8.49(0) | Dy II .24(30) Gd II .39(10) |
| 4128.61(2) | 8.76(3) | 8.74(2) | 8.77(2) | 8.78(2) | Fe II .74(3) |
| 4129.11(1n) | 9.22(3) | 8.96(0) | 9.12(1n) | 9.22(2) | Sm II .23(100) Pr II .15(20) (Ce II .18(5?)) |
| 4129.41(0) | 9.47(1) | | | | Dy II .43(100) |
| 4129.83(8) | 9.94(3) | 9.62(1n) | 9.68(3) | 9.71(8) | Eu II .70(5000) |
| 4130.41(2) | 0.48(1) | 0.26(1) | 0.25(2) | 0.32(2) | Gd II .37(3000) |
| 4130.91(x) | 0.88(x) | 0.87(9) | 0.84(9) | 0.84(9) | Si II .88(10) |
| | 1.19(1) | 1.28(0) | | 1.22(1) | Ce II .10(100) Fe II .17(pr) Dy II .04(6) (Ce II .71(100)) (Nd II .72(3)) (Pr II .77(40)) |
| 4131.46(1) | 1.50(1) | 1.46(0) | 1.39(0) | 1.63(1) | Gd II .48(200) |
| 4131.95(1) | 1.96(1) | 2.01(0) | 1.76(0) | | Fe I .06(300) (A II .73(80)) (La II .74(5)) |
| 4132.29(2) | 2.37(4) | 2.12(1) | 2.19(2) | 2.21(1) | Gd II .28(2000) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4132.48(3) | 2.56(3) | 2.46(2) | 2.48(6) | 2.55(9) | Cr II .44(7) Gd II .28(2000) (Mn II .28(5)) (Pr II .23(30)) (Nd II .55(10)) (La II .50(10)) |
| 4132.80(2) | | | | | Fe I .91(100) (Dy II .85(3)) (O II .82(100)) |
| 4133.45(1) | 3.46(2n) | 3.05(1) | 3.18(2) | 3.24(2) | Eu II .10(6) Nd II .36(50) Dy II .37(8) (La II .33(6)) |
| 4133.62(2n) | 3.72(1) | 3.58(2) | 3.65(2) | 3.68(1) | Ce II .80(500) (Pr II .62(15)) |
| 4134.08(0) | | 4.05(1) | | 3.99(1) | |
| 4134.23(1) | 4.36(1) | 4.48(1) | 4.23(0) | 4.30(0) | |
| 4134.65(0) | 4.84(0) | 4.67(0) | 4.70(1) | 4.72(1) | Fe I .68(150) (Nd II .71(10)) (K II .72(40)) |
| 4134.95(0) | | | | | Eu II .96(5) |
| 4135.40(1n) | 5.39(1n) | 5.26(1) | 5.25(2) | 5.32(3) | Nd II .32(50) Ce II .44(20) |
| 4135.79(0) | 5.98(0) | 5.71(1) | 5.93(0) | 5.81(0) | Cr II .77(pr) (Nd II .79(3)) |
| 4136.30(1) | 6.34(2) | 6.23(1) | 6.30(2) | 6.11(1) | Nd II .23(2) |
| | | | | 6.40(1) | (Eu II .59(20)) |
| 4136.82(1) | 6.90(1) | 6.86(1) | 6.97(4) | 6.85(1) | Mn II .91(2) Nd II .75(10) |
| 4137.01(0) | 7.12(1) | | 7.03(1) | 7.16(2) | Gd II .10(500) Fe I .00(100) |
| 4137.54(1n) | 7.66(1) | 7.52(1) | 7.56(2) | 7.65(1) | Ce II .65(400) |
| 4138.26(2n) | 7.31(2) | 7.21(2) | 7.30(2n) | 7.23(1) | Fe II .21(pr) |
| 4138.88(2) | 8.85(1) | | 8.77(1n) | 8.76(1) | |
| 4139.21(0) | 9.25(0) | 9.19(0) | 9.32(1) | 9.41(1) | |
| 4139.59(1n) | 9.66(1n) | 9.63(3) | 9.74(0) | | Eu II .67(15) |
| | | | | 9.91(1) | Eu II .02(8) (Fe I .92(40)) |
| 4140.40(1n) | 0.47(1) | 0.35(0) | 0.40(1n) | 0.46(2) | Gd II .45(100) |
| 4141.09(1) | 1.10(1) | 0.98(0) | 1.13(1n) | 0.97(1) | Eu II .02(25) Gd II .02(25) |
| | | | 1.22(1n) | 1.38(2) | Pr II .26(80) |
| 4141.66(0) | 1.62(1) | | | 1.66(0) | Eu II .72(40) Dy II .52(40) (La II .73(200)) |
| | 2.10(1) | 2.19(1) | | 2.08(0) | |
| 4142.33(1) | 2.42(1) | | 2.40(1) | 2.48(1) | Ce II .40(150) (S II .29(150)) |
| 4142.73(1) | 2.73(0) | | | | |
| 4143.14(3) | 3.24(2) | 3.04(1) | 3.02(2) | 2.97(2n) | Dy II .10(150) Pr II .14(150) (Fe II .07(pr)) |
| 4143.32(0) | 3.44(0) | 3.53(1) | 3.49(1) | 3.39(2) | Fe I .42(200) |
| 4143.81(4) | 3.90(3) | 3.93(1) | 3.92(2) | 3.98(1) | Fe I .87(400) (La II .77(15)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4144.39(1) | 4.27(1) | 4.37(0) | | 4.32(0) | |
| 4144.56(1) | | | 4.45(1) | 4.49(1) | Tb II .47(100) Ce II .49(10) Eu II .51(8) Nd II .55(20) |
| 4145.09(2) | 5.04(2n) | 5.13(1) | 5.06(3n) | 5.14(4n) | Eu II .23(8) Ce II .00(60) S II .10(250) |
| 4145.67(3) | 5.79(4) | 5.80(3) | 5.84(4) | 5.91(3) | Cr II .80(25) |
| | | | 6.13(1) | | Nd II .13(10) |
| 4146.22(2) | 6.29(2) | 6.31(2) | 6.36(0) | 6.32(1) | Ce II .23(75) (Eu II .32(4)) |
| 4146.59(0) | 6.49(1) | 6.50(1) | 6.50(0) | 6.64(0) | Cr II .45(1) (Pr II .54(15)) |
| 4147.12(2) | 7.24(2n) | 7.18(1) | 7.10(1) | 7.12(2n) | Eu II .22(12) |
| 4147.46(2) | 7.56(1) | 7.64(0) | | 7.70(1) | Fe I .67(200) |
| 4148.11(0) | 8.05(1) | 8.10(1) | 8.19(1) | 8.18(1) | |
| 4148.29(2n) | 8.37(1) | | | 8.28(2) | Eu II .40(8) (Pr II .46(15)) (La II .2(4)) |
| 4148.80(1) | 8.90(1) | 8.93(0) | 8.90(1) | | Ce II .90(25) |
| 4149.25(2) | 9.24(1) | | 9.18(1) | 9.10(3n) | Zr II .22(75) Fe I .37(100) (Tb II .16(6)) (K II .17(20)) |
| 4149.89(1) | | 9.80(1) | 9.86(2) | 9.79(0) | Sm II .83(200) |
| 4149.93(1) | 0.02(2) | | | 9.96(2n) | Ce II .94(60) Pr II .04(10) |
| 4150.38(0) | | 0.20(1) | 0.26(0) | 0.34(0) | Fe I .26(50) Eu II .31(8) |
| | 0.59(1) | | | 0.68(1) | Gd II .61(20) |
| 4150.87(3) | 1.03(3) | 0.93(2) | 0.97(3) | 1.02(4) | Cr II .00(5) Eu II .19(12) (Zr II .97(10)) (La II .97(12)) |
| 4151.54(0) | 1.52(1) | | | 1.51(0) | Gd II .63(30) Eu II .52(20) N I .46(1000) |
| 4151.97(1n) | 2.00(1) | 1.80(1) | 1.90(1n) | 1.98(1n) | Ce II .97(200) Sm II .21(200) Fe I .17 (70) (La II .98(250)) (Gd II .03(10)) |
| 4152.46(1) | 2.38(0) | 2.47(0) | 2.42(0) | 2.47(1) | Dy II .43(1) |
| 4152.89(2n) | 2.89(1) | | | 2.60(0n) | La II .78(100) (Fe II .98(pr)) |
| | | 3.11(1) | 3.00(1) | 3.13(1) | S II .10(600) |
| 4153.45(0) | | | | | Gd II .51(125) Eu II .44(8) (O II .31(200)) |
| 4153.81(1n) | 3.87(2n) | 3.78(1) | 3.77(1n) | 3.64(1) | Fe I .91(120) (Nd II .73(4)) (Ce II .67(pr)) |
| 4154.28(0) | 4.23(0) | | | 4.15(0) | Dy II .22(2) Cr II .29(pr) |
| 4154.64(1n) | 4.65(1n) | 4.64(1n) | 4.71(2) | 4.63(1) | Fe I .50(100) Fe I .81(100) (Gd II .86(250)) |
| 4155.29(0) | 5.30(1) | 5.34(0) | 5.36(1) | | Sm II .32(100) Sm II .22(100) |
| 4155.85(0) | 5.68(0) | 5.90(0) | 5.73(1) | 5.55(0) | Nd II .08(250) Ce II .53(6) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4156.20(3) | 6.31(1n) | 6.02(0n) | 6.04(3) | 6.15(3) | Zr II .24(15) Nd II .26(30) |
| 4157.02(1) | 6.90(1) | | 6.82(1n) | 6.86(2) | Fe I .80(100) |
| | 7.39(0) | | | 7.33(0) | |
| 4157.56(1) | 7.61(1) | 7.56(1n) | 7.54(1n) | 7.64(1) | Nd II .58(3) |
| 4157.91(0) | 7.93(1) | | | 7.72(1) | Fe I .79(150) Dy II .86(1) |
| 4158.38(0) | 8.44(1) | | 8.24(0) | 8.31(1) | A I .59(1200) (Tb II .28(6)) |
| 4158.81(0) | 8.81(0) | 8.91(1) | 8.86(1) | 8.81(1) | Fe I .80(100) |
| 4159.02(0) | 9.11(1) | 9.18(0) | | 9.14(0) | Ce II .03(50) |
| | 9.45(0) | 9.53(0) | | 9.57(1) | Al II .45(4) Al II .41(2) (Ti I .64(60)) (Nd II .56(4)) |
| 4159.75(0) | 9.84(0) | 9.94(1) | 9.97(1) | 9.92(1) | Al II .72(6) Al II .81(4) |
| 4160.24(1) | 0.22(0) | | | 0.05(1) | Al II .24(12) Al II .26(15) |
| 4160.66(2) | 0.59(1) | 0.54(3) | 0.52(3) | 0.58(4) | Eu II .48(12) Nd II .56(30) (P II .56(30)) |
| 4161.21(1) | 1.14(1n) | 1.10(2) | 1.08(2) | 1.18(3) | Ce II .14(50) Ce II .18(18?) Cr II .05 (2) (Cr II .27(pr)) (Zr II .20(20)) |
| 4161.52(1) | 1.59(1) | | | | Ti II .54(30) (Cr II .56(pr)) |
| 4161.88(3) | 1.82(1) | 1.71(1) | 1.71(2) | 1.75(3) | (Sr I .80(30)) |
| 4162.30(1) | 2.33(0) | | 2.20(0) | 2.03(1) | Eu II .14(8) |
| 4162.75(1n) | 2.78(1n) | 2.62(1) | 2.62(2n) | 2.73(2n) | Gd II .73(500) (S II .70(600)) |
| 4163.25(0) | 3.24(0) | 3.43(1) | | | |
| 4163.56(4) | 3.68(4n) | 3.56(3) | 3.54(4) | 3.62(4) | Ti II .65(150) (Ce II .52(20)) (Cr I .62(100)) |
| 4163.73(1) | | 3.88(1) | | | |
| 4164.13(0) | 4.26(1) | | 4.17(1) | 4.28(1) | Pr II .19(100) A I .18(1000) |
| | 4.47(0) | | | 4.47(1n) | |
| 4164.64(2) | 4.78(1n) | 4.63(1n) | 4.87(1) | 4.96(1) | |
| 4165.16(1) | 5.15(1) | | | 5.02(2) | Nd II .04(5) |
| 4165.65(1) | 5.65(1) | 5.60(0) | 5.60(2) | 5.62(1) | Ce II .61(200) (Cr I .52(80)) |
| | 5.91(1) | | | 5.90(1) | |
| 4166.19(1) | 6.35(1) | | 6.17(0) | 6.31(0) | |
| 4166.83(4) | 6.90(3) | 6.74(1n) | 6.63(2) | 6.71(2) | Fe II .70(tr) (P II .73(15)) |
| 4167.32(1) | 7.15(2n) | 7.12(1) | 7.13(1n) | 7.08(1) | Gd II .16(40) (Mg I .39(6)) (Dy II .40(2)) |
| 4167.73(1) | 7.75(1n) | 7.64(1) | 7.67(1) | 7.62(0) | Ce II .80(12?) |
| | 8.21(0) | 8.50(0) | 8.28(0) | 8.42(1) | (S II .41(50)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4168.57(1) | 8.61(1) | | 8.76(0) | 8.74(0) | (Fe II .66(pr)) (Nd II .76(3)) |
| 4168.98(0) | 9.10(0) | | | | |
| 4169.34(0) | 9.51(0) | | | 9.30(0) | Sm II .48(200) Eu II .35(5) Pr II .46(15) (Dy II .24(2)) |
| 4169.73(1n) | 9.60(1) | 9.73(1n) | 9.78(2) | 9.61(0) | Ce II .77(12?) (Cr I .84(80)) |
| | 9.96(2) | | 9.93(0) | 9.93(1) | Gd II .11(150) Ce II .88(30) (Fe II .98(pr)) |
| 4170.57(1) | 0.61(2) | | | 0.42(1) | Cr II .58(pr) (Nd II .45(4)) |
| 4170.96(3) | 0.93(2n) | 0.79(2) | 0.79(3n) | 0.86(6) | Cr II .86(1) Fe I .91(80) (Nd II .75(6)) |
| 4171.34(0) | 1.38(1) | | 1.36(0) | 1.40(1) | |
| 4171.87(8) | 1.97(7) | 1.92(4) | 1.98(4n) | 1.92(6) | Ti II .90(70) Cr II .92(3) (Pr II .82(40)) |
| 4172.07(1) | | | | | Fe I .13(80) |
| | | | | 2.34(1) | Pr II .27(50) |
| 4172.46(2) | 2.59(3) | 2.63(3) | 2.66(2) | | Cr II .60(2) |
| 4172.87(2) | 2.88(0) | | | 2.76(2) | Eu II .80(30) Fe I .75(60) |
| 4173.41(9) | 3.46(9) | 3.41(6) | 3.45(6) | 3.50(8) | Fe II .45(8) Ti II .55(40) Gd II .56(100) (Nd II .38(8)) |
| 4174.06(2) | 4.25(2) | 4.13(1) | 3.88(0) | 4.07(1) | Ti II .09(12) (Fe I .93(50)) (S II .04(50)) (Mn II .31(pr)) |
| 4174.61(0) | 4.54(0) | | 4.41(0) | 4.48(0) | |
| | 4.91(0) | | | 4.75(1) | Fe I .92(100) (Cr I .80(100)) |
| 4175.17(0n) | 5.39(0) | 5.07(0) | 5.35(0) | 5.34(1) | Eu II .16(12) Pr II .30(15) |
| 4175.62(1n) | 5.77(2n) | 5.84(1) | 5.84(1n) | 5.85(1) | Fe I .64(100) Nd II .61(50) (Pr II .64(15)) |
| | 6.02(1) | | | 6.27(0) | Ce II .08(12?) |
| 4176.59(1n) | 6.43(0) | 6.55(1n) | | | Fe I .57(100) Eu II .62(8) (Mn I .60(100)) |
| 4176.83(1n) | 6.70(2n) | | 6.66(2) | 6.73(3) | (Gd II .79(15)) |
| | | | 7.18(1) | 7.33(0) | Nd II .32(200) (Eu II .37(5)) |
| 4177.56(5) | 7.66(5n) | 7.62(4) | 7.70(7) | 7.76(6) | Fe I .60(100) Eu II .57(15) (Y II .55(50)) (Fe II .70(pr)) |
| 4177.91(3) | 7.98(1) | | | 8.11(0) | Sm II .02(100) |
| 4178.29(0) | 8.38(0) | 8.31(7) | 8.36(1) | 8.48(1) | Nd II .64(15) Pr II .64(20) (Nd II .44(6)) (Nd II .53(8)) |
| 4178.77(5) | 8.82(7) | 8.82(5) | 8.85(5) | 8.94(4) | Fe II .86(8) (Tb II .97(15)) |
| 4179.34(5) | 9.44(6) | 9.46(3) | 9.42(4) | 9.52(3) | Cr II .46(12) Pr II .42(150) (Nd II .58(30)) (Cr I .26(100)) (Eu II .37(4) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4179.91(1) | 0.00(1n) | 9.99(0) | 9.90(0) | 9.97(0) | Eu II .88(8) Zr II .81(15) (Cr II .92(pr)) |
| 4180.40(1) | 0.46(1) | 0.44(0) | | 0.41(1) | |
| | | | 0.71(2n) | 0.67(0) | Pr II .68(8) |
| 4181.04(3) | 1.03(1) | 0.83(1n) | 0.89(0n) | 0.91(2n) | Yb II .83(40) (Ti I .87(100)) |
| 4181.26(0) | | | | | Ti II .17(pr) |
| | | | 1.48(1) | 1.49(0) | Cr II .50(1) |
| 4181.66(1) | 1.69(1) | 1.75(1n) | | 1.77(0) | Fe I .76(200) (A I .88(1000)) |
| | 1.99(0) | | | 1.98(2) | |
| 4182.17(1) | 2.18(2n) | 2.11(1n) | 2.13(2n) | 2.30(2) | Nd II .29(2) |
| 4182.50(0) | 2.62(0) | 2.59(0) | 2.74(0) | 2.68(0) | Dy II .42(8) Fe I .39(80) (Nd II .51(4)) |
| | 2.98(0) | | | 2.84(0) | |
| 4183.29(1) | 3.39(2) | 3.36(1) | 3.30(2n) | 3.40(1n) | V II .44(250) |
| 4183.86(1) | 3.81(1) | | | 3.89(0) | Sm II .76(150) (Eu II .78(4)) |
| 4184.29(3) | 4.28(3n) | 4.21(1) | 4.23(4) | 4.24(6) | Gd II .25(2000) Lu II .26(120) (Pr II .24(8)) (Ti II .33(20)) |
| 4184.87(0) | 4.83(1) | 4.86(1) | 4.81(1) | 4.90(1) | Fe I .90(100) (Eu II .98(6)) (Nd II .98(15)) |
| 4185.26(0) | 5.26(0) | | | 5.23(0) | Ce II .33(5?) Pr II .15(10) |
| 4185.60(0) | 5.52(0) | | 5.61(1) | 5.58(1) | Cr II .50(pr) (O II .45(150)) |
| 4186.07(0) | 6.11(1) | 5.97(0) | 6.13(0) | 6.14(0) | Fe I .12(100) Cr II .08(pr) Nd II .03(8) (K II .23(60)) |
| 4186.62(1n) | 6.62(2n) | 6.51(1) | 6.52(2) | 6.62(2) | Ce II .60(600) (Zr II .70(12)) |
| 4187.20(1) | 7.11(1) | 7.07(1) | 7.19(2) | 7.17(1) | Fe I .04(250) |
| 4187.44(0) | 7.41(1) | | | | Ce II .32(35?) |
| 4187.73(2) | 7.82(3) | 7.73(2) | 7.78(2n) | 7.87(2n) | Fe I .80(200) Gd II .10(60) (Gd II .96(10)) |
| 4188.23(1) | 8.30(1) | 8.24(0) | | | Sm II .13(200) Gd II .10(60) |
| | | | 8.50(0) | 8.58(1) | (Tb II .53(8)) |
| 4188.79(3) | 8.77(1) | | | | |
| 4189.04(2) | 8.97(2n) | 8.89(1) | 8.91(1n) | 9.01(1) | |
| 4189.46(1) | 9.51(1) | 9.44(0) | 9.40(1) | 9.59(1) | Pr II .52(125) (S II .71(250)) |
| 4189.83(1) | | | | 9.86(0) | Eu II .75(5) O II .79(500) |
| 4190.09(3) | 0.04(2n) | 0.04(1) | 0.07(2) | 0.11(1) | |
| 4190.64(2) | 0.76(3) | 0.73(3) | | 0.64(0) | Si II .74(3) Ce II .63(30) (A I .71(600)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4191.22(2) | 1.30(2) | 1.27(0) | 0.89(2n) | 1.02(3n) | Gd II .07(800) (A I .03(1200)) (Gd II .36(10)) (Cr I .27(70)) |
| 4191.53(0) | 1.45(1) | 1.54(1) | 1.52(1n) | 1.54(1n) | Fe I .44(200) (Pr II .62(20)) (Zr II .50(6)) |
| 4191.75(0) | 1.87(0) | | | 1.76(1) | (Cr I .75(50)) |
| 4192.04(1) | | | | | Ni II .07(1) |
| 4192.43(1n) | 2.39(0) | 2.28(0) | | 2.25(1) | La II .35(100) |
| 4192.82(0) | | | | | Eu II .62(12?) |
| 4193.19(1) | 3.14(1n) | 2.98(1) | 3.07(2) | 3.02(0n) | Gd II .15(60) Ce II .09(50) |
| | | 3.47(0) | | 3.41(0) | Mg II .44(?) |
| 4193.76(1) | 3.94(1n) | 3.98(0) | 3.84(1) | 3.90(3) | Ce II .87(35?) (Cr I .66(100)) ? |
| 4194.13(2) | 4.02(0n) | | | | |
| | | | 4.25(0) | 4.38(1) | La II .36(30) |
| 4194.68(1) | 4.82(0) | 4.71(1) | 4.89(0) | 4.69(0) | |
| 4194.92(0) | | | 4.92(0) | 5.01(1) | Nd II .03(30) |
| 4195.28(4) | 5.42(5) | 5.39(3) | 5.46(2) | 5.47(1) | Cr II .41(10) Fe I .34(150) Gd II .41(60) (Eu II .36(10)) |
| 4195.54(0) | | | | 5.58(1) | Fe I .62(25) |
| 4196.00(1) | 5.79(0) | | | 5.94(0) | Gd II .85(20) |
| 4196.19(3n) | 6.19(3n) | 6.13(2) | 6.19(1n) | 6.15(3) | Fe I .21(100) Eu II .18(15) Ce II .34(75) |
| | | | | 6.32(1) | Ce II .34(75) |
| | | 6.69(0) | | | La II .55(250) |
| 4196.91(1n) | 7.06(1n) | 7.00(0) | 6.87(1) | 6.85(1) | Gd II .07(150) |
| | 7.40(0) | 7.35(0) | 7.29(1) | | (Cr I .23(70)) |
| 4197.62(1) | 7.76(1) | 7.67(0) | 7.57(2) | 7.62(1n) | Gd II .68(800) (Ce II .67(4?)) |
| 4198.09(3) | 8.16(3n) | 8.11(2n) | | | Si II .17(2) (Ce II .00(5?)) (Nd II .17(2)) (Ti II .95(pr)) |
| | 8.39(1) | | 8.27(2n) | 8.30(1n) | Fe I .31(250) |
| 4198.61(1) | | 8.51(1n) | 8.60(1n) | 8.54(1) | Cr I .52(100) (Ce II .43(4?)) |
| | 8.83(1) | | 8.67(0) | 8.77(1) | Ce II .67(75) Ce II .72(60) |
| 4199.02(1) | 9.06(2) | 8.96(1) | 9.10(1) | 9.15(1) | Fe I .10(300) (Nd II .10(10)) (Cr II .02(pr)) |
| 4199.43(2) | 9.47(2n) | 9.41(2n) | 9.52(2) | 9.57(2) | |
| 4199.74(0) | | | | 9.68(1) | |
| 4199.95(0) | 9.88(1) | | | | Tm II .92(100) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4200.06(1) | | 0.02(0) | | 0.13(1) | Mn II .25(2) Nd II .03(3) |
| 4200.51(4n) | 0.64(4n) | 0.72(3n) | 0.54(3n) | 0.61(3) | A I .68(1200) (?Ti II .40(pr)) |
| 4200.79(3n) | 0.86(4) | | 0.82(0) | | Fe I .93(80) |
| 4201.22(0) | | | 1.13(1n) | 1.23(2n) | Pr II .18(15) Tb II .00(30) |
| 4201.43(2) | 1.43(1) | | | 1.62(0) | Dy II .37(10) Pr II .53(10) |
| 4201.92(3) | 1.96(2) | 1.91(1) | 2.11(1n) | 2.06(1) | Fe I .03(400) |
| 4202.43(4) | 2.48(3) | 2.28(1) | 2.53(0) | 2.43(2) | Gd II .52(80) (V II .35(150)) (Al II .4(8)) |
| 4202.94(1) | 2.81(2n) | 2.75(1n) | 2.90(4) | 2.98(3) | Ce II .94(150) Sm II .05(125) |
| 4203.48(1n) | 3.59(1) | 3.39(1) | 3.47(1) | 3.43(1) | (Cr I .59(100)) (Nd II .43(2)) |
| 4204.00(2) | 4.06(1) | 3.98(0) | 3.96(0) | 3.88(1) | Fe I .99(200) (La II .03(100)) |
| 4204.63(0) | 4.52(0) | | 4.41(0) | 4.56(0) | Cr II .66(pr) |
| 4205.10(8n) | 5.28(4n) | 4.79(1n) | 4.88(4) | 4.95(9) | Eu II .05(6000) Gd II .86(300) (V II .08(250)) (Cr II .83(pr)) |
| 4205.33(1n) | 5.38(3n) | | | | Nd II .26(10) Fe II .48(pr) (Mn II .37(pr)) |
| 4205.42(3) | 5.54(3n) | 5.53(2n) | 5.54(2) | 5.59(3) | Nd II .60(40) (Fe I .55(50)) (Eu II .57(5)) |
| 4205.75(1n) | | | | | |
| | 5.95(0) | | 6.07(0) | 6.08(2) | Sm II .13(100) (Ti II .92(pr)) (Zr II .91(2)) |
| 4206.28(3) | 6.35(2) | 6.38(1n) | 6.45(1) | 6.42(1) | Mn II .43(2) Dy II .54(40) |
| 4206.67(1) | 6.75(1) | | | 6.85(1) | Fe I .70(125) Pr II .74(100) |
| 4207.02(0) | | | | | Fe I .13(80) |
| 4207.27(3) | 7.30(3) | 7.31(1) | 7.45(2n) | | Cr II .35(4) (Mn II .23(pr)) |
| 4207.79(3n) | 7.83(3) | 7.74(0) | 7.79(1) | 7.63(4) | (Pr II .81(8)) (La II .61(10)) |
| | 7.98(0) | | | 7.91(1) | |
| 4208.10(1) | 8.23(1) | 8.40(0) | 8.34(1) | 8.37(2) | Gd II .37(8) (Eu II .17(5)) (Pr II .30(15)) (Cr I .36(100)) |
| 4208.56(1) | 8.55(1) | 8.52(0) | | | Fe I .62(100) |
| 4208.99(3) | 9.09(2) | 9.15(1) | 9.05(1) | 9.02(1) | Cr II .02(3) (Zr II .99(30)) (Gd II .75(8)) |
| 4209.51(1) | 9.53(1) | | | 9.56(0) | Ce II .41(25?) |
| 4209.74(0) | 9.79(1) | 9.70(1) | 9.85(0) | 0.03(1) | Cr II .84(pr) |
| 4210.22(1) | 0.27(1) | 0.24(1n) | 0.40(2) | 0.48(1) | Fe I .35(300) Sm II .35(150) (La II .22(50)) |
| 4210.64(0) | 0.67(1) | 0.79(0) | | | (Zr II .62(5)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4210.93(1n) | 1.08(1) | | | 1.06(1) | |
| | 1.33(1) | 1.19(1) | 1.12(1n) | 1.40(1) | Eu II .28(10) Nd II .29(40) (Cr I .35(100)) |
| 4211.70(0) | 1.84(1) | | | | Zr II .88(12) Pr II .86(20) |
| 4211.95(3n) | 2.05(1) | 1.83(1) | 1.86(4) | 1.90(6) | Gd II .00(800) |
| 4212.60(1) | 2.41(0) | 2.46(0) | 2.47(0) | 2.52(2) | |
| 4212.74(1) | 2.75(1) | 2.77(0) | | | Nd II .75(6) |
| | 3.07(0) | | 2.98(1) | 3.07(1) | Ce II .04(15) (Nd II .06(4)) |
| 4213.33(1) | 3.42(1n) | 3.45(1n) | 3.47(2) | | Eu II .48(4) (Nd II .21(5)) |
| 4213.63(0n) | 3.68(1) | | 3.56(1) | 3.59(1) | Fe I .65(100) (Tb II .50(30)) (Pr II .57(10)) |
| 4214.03(1) | 4.12(1) | 3.87(1) | 4.05(1) | 4.17(1) | Ce II .04(50) (Nd II .23(4)) |
| 4214.45(0) | 4.55(1) | 4.46(0) | | | Gd II .58(20) (Nd II .60(12)) (Tb II .42(15)) |
| 4215.01(2) | 5.04(1) | 4.85(1) | 4.88(1n) | 4.86(2n) | Gd II .02(600) |
| 4215.40(1n) | | 5.39(1) | | | |
| 4215.63(6n) | 5.64(5) | 5.62(3) | 5.55(3) | 5.58(4) | Sr II .52(400) (Cr II .77(2)) (Zr II .76(1)) |
| 4216.07(0) | 6.24(1) | | 5.85(1) | 6.09(1) | Fe I .19(200) |
| 4216.47(1) | | 6.57(1) | 6.51(1) | 6.40(0) | |
| 4216.92(0) | 7.02(1n) | 6.98(1) | | 6.95(0) | Cr II .87(1) Cr II .07(1) |
| 4217.24(1n) | 7.20(1) | 7.18(1) | 7.14(4) | 7.27(4) | Gd II .20(500) (Nd II .28(5)) (S II .23(30)) |
| 4217.61(1n) | 7.58(1) | | 7.60(0) | 7.57(0) | Fe I .56(100) Ce II .59(30) La II .56(200) (Cr I .63(150)) |
| 4217.82(1) | 7.98(2n) | 7.80(1n) | 7.89(2) | 8.00(3) | Eu II .75(10) |
| 4218.26(0) | 8.28(1) | | | | (Ti II .18(pr)) |
| 4218.62(0) | 8.71(1) | | | 8.46(1) | Eu II .45(6) Dy II .58(5) (Nd II .55(3)) |
| 4219.24(1) | | | 8.91(0) | 8.98(1) | Eu II .03(10) |
| | 9.38(1n) | 9.38(1) | 9.41(0n) | 9.49(1) | Fe I .36(250) |
| 4219.61(1) | 9.74(1) | 9.57(1n) | 9.51(1) | 9.55(0) | Pr II .65(15) (Nd II .57(4)) (Ne II .76(100)) |
| 4220.14(0) | | | | 0.03(0) | Nd II .26(20) (Tb II .12(6)) |
| 4220.28(1) | 0.34(0) | 0.45(0n) | 0.44(0n) | 0.49(0) | Fe I .35(80) Sm II .66(200) |
| | 0.82(0) | 0.91(0) | | | (Ne II .92(15)) |
| 4221.18(0) | 1.24(1) | 1.29(0) | | 1.35(1) | Eu II .08(25) Nd II .33(80) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4221.86(1) | 1.98(1) | 1.92(1) | | | Cr II .00(1) |
| 4222.13(0) | 2.01(1) | 2.03(0) | 2.09(0) | 2.16(1) | Fe I .22(200) Cr II .00(1) |
| 4222.45(1) | 2.67(2) | 2.36(0) | 2.36(0) | 2.57(1) | Ce II .60(300) (Zr II .41(3)) |
| 4222.81(1n) | 2.94(2) | 2.85(2) | 2.93(3) | 3.01(3n) | Gd II .02(60) Pr II .98(150) (Nd II .21(5)) (Cr I .73(100)) (K II .98(40)) |
| 4223.60(1) | 3.71(1) | 3.66(0) | 3.56(0n) | 3.63(1) | |
| 4223.89(1) | 4.04(1) | 4.00(1) | | | Eu II .88(15) (Cr II .09(pr)) |
| 4224.34(3) | 4.39(1) | 4.24(1) | 4.17(4) | 4.24(4) | Fe I .18(200) Cr II .09(pr) (Zr II .27(3)) |
| | | 4.66(0) | | 4.65(1) | |
| 4224.76(2) | 4.84(4) | 4.87(2) | 4.92(3) | 5.01(2) | Cr II .85(20) (Nd II .85(8)) |
| 4225.11(0) | | 5.17(1) | | | Gd II .15(100) (V II .23(120)) |
| 4225.31(2) | 5.39(2) | | 5.26(2) | 5.36(1) | Sm II .33(400) V II .23(120) (Pr II .33(150)) |
| 4225.68(0) | 5.79(0) | | | 5.86(0) | Eu II .68(8) (K II .60(40)) |
| 4226.05(1) | 6.14(1) | 6.15(1) | 6.08(1) | 6.21(0) | |
| 4226.78(1) | 6.80(1) | | | 6.60(1) | Ca I .73(500) Al II .81(35) Eu II .87 (4?) (Nd II .99(4)) (Cr I .76(125)) |
| | | | 7.25(1n) | 7.16(1n) | Gd II .14(200) (Ti II .34(pr)) |
| 4227.30(5) | 7.39(4) | 7.40(2n) | 7.50(1n) | 7.51(1n) | Fe I .43(300) Eu II .40(6) (Al II .50(30)) (Al II .41(8)) |
| 4227.74(1) | 7.84(1) | | | 7.79(1) | Ce II .75(100) Cr II .73(1) Nd II .72(30) |
| 4228.07(0) | | 8.06(0) | | | (Al II .98(20)) (Eu II .04(3)) (Nd II .02(10)) |
| 4228.37(1) | 8.33(1) | 8.44(1n) | 8.30(2) | 8.41(3) | Nd II .20(8) Nd II .57(2) |
| 4228.74(1) | 8.72(1) | | | 8.90(0) | Nd II .84(2) |
| 4229.36(0) | 9.27(1) | 9.22(1) | | | Eu II .33(12) |
| 4229.67(1) | | 9.63(0) | 9.42(2) | 9.59(2n) | Sm II .70(300) Eu II .52(5) (Nd II .52(5)) |
| | 9.81(1n) | 9.99(0) | 9.80(0) | 9.95(0) | Gd II .80(200) Cr II .81(1) |
| 4230.33(1) | 0.15(1) | 0.37(0) | | | |
| 4231.08(1) | 0.84(0) | 0.93(0) | 0.81(0) | 0.74(0) | Eu II .63(12?) La II .95(150) Gd II .03(5) (S II .98(35)) |
| 4231.71(1) | 1.80(1) | | 1.62(1) | 1.60(0) | Ce II .74(30) (Zr II .64(8)) (Ne II .60(50)) |
| 4232.22(0) | | | | 2.22(0) | Nd II .38(150) Tb II .20(20) (Cr I .22(70)) |
| 4232.49(0) | 2.53(1) | | | | Gd II .47(40) Eu II .45(12) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4233.11(x) | 3.17(x) | 3.14(x) | 3.20(9) | 3.21(9) | Fe II .17(11) Cr II .25(10) (Pr II .13(10)) |
| 4233.51(1) | 3.65(1) | 3.70(0) | | | Fe I .61(250) |
| 4233.87(1n) | 3.98(2) | 3.95(1n) | 3.83(1n) | 3.86(3) | |
| 4234.06(1) | 4.31(0) | | | 4.25(0) | Eu II .09(8) Nd II .20(6) (Cl II .09(50)) |
| 4234.72(0) | | 4.53(0) | 4.61(1) | 4.65(0) | Sm II .57(200) Ce II .73(12) (V II .55(40)) |
| | 4.87(0) | | 4.96(0) | 4.86(0) | Gd II .07(15) |
| 4235.28(1n) | 5.34(2n) | 5.29(1) | 5.38(2n) | 5.37(1n) | Mn (II?) .29(80) (Nd II .23(6)) |
| | | | | 5.71(1) | Eu II .72(12) |
| 4235.86(2) | 5.95(2) | 5.91(1) | 5.86(2) | 6.05(1) | Fe I .94(300) Gd II .88(60) |
| 4236.38(1) | 6.47(2) | 6.44(1) | 6.45(1) | 6.48(1) | Eu II .22(8) Pr II .21(25) (Cr II .33(pr)) (Zr II .56(5)) |
| 4236.72(0) | 6.66(0) | | 6.82(1) | 6.65(1n) | Sm II .74(250) (Pr II .64(10)) |
| 4236.98(0) | 7.08(0) | 6.97(1) | 7.11(0) | 6.94(0) | |
| 4237.45(0n) | 7.66(1) | 7.64(0) | 7.31(0) | 7.41(1) | Sm II .66(200) Eu II .51(40) (Dy II .54(2)) (Cr I .71(70)) |
| | 7.98(1) | 7.95(1) | 7.94(1) | 8.01(1) | (Dy II .04(1)) |
| 4238.16(1) | | 8.21(1n) | | 8.33(0) | La II .38(400) (Dy II .44(2)) |
| 4238.78(3n) | 8.78(2n) | 8.72(3) | 8.75(2) | 8.77(1) | Gd II .78(500) Fe I .82(200) (Eu II .69(20)) (Cr II .69(pr)) |
| | 9.26(1) | | | | Cr II .31(0) |
| 4239.69(2n) | 9.73(2) | 9.75(2) | 9.54(1) | 9.68(1) | (Mn I .72(100)) |
| | 9.92(1) | | 9.93(2) | 0.02(0) | Ce II .91(200) Pr II .03(20) (Nd II .83(10)) (Tb II .14(15)) |
| 4240.40(1) | 0.48(1) | 0.51(1) | 0.43(2) | 0.52(1) | (Eu II .21(4)) (Eu II .38(5)) |
| 4240.64(0) | | | | 0.89(1) | Al II .75(15) Eu II .83(6) (Cr I .70(200)) |
| 4241.20(2) | 1.12(1) | 1.20(1) | 1.12(2n) | 1.18(3n) | Gd II .28(80) Pr II .02(60) (Nd II .21(4)) (La II .20(15)) |
| | 1.45(1) | | | | Gd II .28(80) (Cl II .38(60)) |
| 4241.66(0) | 1.72(1) | 1.67(0) | 1.79(1) | 1.87(1) | (Eu II .60(10)) |
| 4242.24(6) | 2.29(9) | 2.38(6) | 2.40(5) | 2.46(2) | Cr II .38(30) (Mg II .47(4)) (Mn II .30(2)) (Tb II .57(12)) |
| 4242.79(1) | 2.82(1) | 2.94(0) | | 2.84(1) | Ce II .72(15) |
| 4243.08(0) | 3.12(1) | 3.18(0) | 3.04(1) | 3.08(0) | |
| 4243.43(0) | 3.44(0) | 3.53(1) | | | (Pr II .53(20)) |
| 4243.87(3) | 3.90(1) | | 3.63(3) | 3.64(3) | Gd II .84(150) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4244.37(1) | 4.35(1) | 4.14(1) | 4.15(1) | 4.18(1) | Mn II .25(1) Eu II .41(6) |
| | | | 4.48(1) | | Eu II .41(6) |
| | | | 4.68(0) | 4.66(2) | Sm II .70(200) |
| 4244.88(1) | 5.02(1) | 5.06(0) | 4.91(0) | | Ni II .80(1) Cr II .08(1) (Dy II .79(1)) (Nd II .97(3)) |
| | | | 5.26(1) | 5.20(1) | Fe I .26(80) Cr II .08(1) |
| 4245.36(1) | 5.43(1) | | | | Eu II .46(10) |
| 4245.79(0) | | 5.71(1) | 5.79(1) | 5.66(0) | (Eu II .85(3)) |
| 4246.18(1) | 5.99(1) | | | 5.99(1) | Fe I .09(80) (Ce II .98(6)) (F II .16(300)) |
| | 6.40(2) | 6.36(2) | 6.46(2) | 6.51(2) | Gd II .57(150) Cr II .41(2) |
| 4246.70(1) | 6.76(1) | | | | Ce II .71(30?) |
| 4246.97(0) | | | 6.92(0) | | Sc II .83(500) Nd II .88(10?) (Cr II .88(1)) |
| 4247.11(0) | 7.17(1) | 7.19(1) | | 7.22(1) | Eu II .06(25) |
| 4247.37(3) | 7.44(2) | 7.31(0n) | 7.33(1) | | Fe I .43(200) Dy II .37(20) (Nd II .37(200)) |
| | 7.89(1) | | | 7.83(0) | Eu II .88(6) Mn II .95(1) Pr II .66(60) |
| 4248.07(1) | 8.12(1) | 8.10(0) | 8.10(0n) | 8.22(0) | Fe I .23(150) |
| 4248.55(1) | 8.72(1) | 8.52(1) | 8.71(1) | 8.80(1) | Ce II .68(200) (Dy II .44(2)) (Tb II .59(4)) |
| 4248.94(1) | | 9.02(0) | | | Pr II .08(10) |
| 4249.48(0) | 9.47(0) | 9.36(0) | | 9.50(1) | Pr II .48(15) |
| 4249.94(1) | 0.01(1) | | | 9.91(0) | La II .99(100) |
| | | 0.24(1) | 0.14(1) | 0.27(1n) | Fe I 13(250) |
| 4250.47(3n) | 0.40(2) | 0.54(1) | 0.40(2n) | 0.54(1) | Cr II .51(1) Pr II .40(20) (Mo II .69(125)) (Ne II .68(50)) |
| | 0.86(1) | 0.84(1) | 0.78(0) | | Fe I .79(400) |
| 4251.03(1) | 1.17(1) | 1.14(0) | 1.17(0) | 1.14(0) | |
| 4251.61(1n) | 1.77(1) | 1.70(1n) | 1.71(4) | 1.75(5) | Gd II .73(2000) Mn II .77(2) (Sm II .79(200)) (Pr II .49(20)) |
| 4251.95(2n) | 2.16(0) | 2.33(0) | 2.30(1) | 2.29(0) | (Ti II .05(pr)) |
| 4252.50(6) | 2.63(4) | 2.64(3) | 2.68(5) | 2.74(3) | Cr II .66(10) (Nd II .44(40)) |
| 4252.95(1) | 3.04(1) | | | | Mn II .02(2) (La II .92(4)) |
| 4253.46(2n) | 3.54(1) | 3.34(1) | 3.33(2n) | 3.38(3n) | Gd II .37(800) Ce II .36(50) (Gd II .61(800)) (Cl II .51(75)) |
| | 3.94(0) | | 4.11(1) | 4.21(0) | Eu II .80(20) (O II .98(100)) (Nd II .87(3)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4254.35(3) | 4.44(4) | 4.44(4) | 4.53(4) | 4.57(2n) | Cr I .35(5000) Pr II .42(20) Er (II?) .32(S1) |
| 4254.85(0) | 4.87(1) | | | 4.96(0) | |
| 4255.16(0) | | | 5.26(0) | | |
| 4255.60(2) | 5.43(0) | 5.59(1) | | | Gd II .57(20) Gd II .41(15) |
| | 5.76(1) | 5.68(3) | 5.75(2) | 5.77(1n) | Ce II .78(60) |
| 4255.98(2) | 6.10(3n) | 6.11(3n) | 6.17(4) | 6.24(3) | Cr II .16(5) (Ti I .04(80)) (Ce II .16(5)) (Nd II .24(8)) (Dy II .97(1)) (Dy II .20(3)) |
| 4256.39(1) | 6.40(1) | | | | Sm II .39(400) Dy II .32(80) |
| | | | 6.63(0) | 6.62(1) | |
| 4256.76(1) | 6.84(1) | | | 6.96(0) | Nd II .82(8) |
| 4257.19(1) | 7.20(0) | 7.03(0) | 7.13(0) | 7.16(0) | Ce II .12(20) (Eu II .08(4)) |
| 4257.32(0) | 7.38(1) | 7.50(1) | 7.54(1) | 7.57(1) | (S II .42(30)) |
| 4257.77(0) | 7.69(0) | | | | Mn 1 .66(100) Eu II .85(4) (Nd II .78(4)) (Dy II .72(1)) |
| 4258.11(8) | 8.17(5) | 8.14(5) | 8.21(7) | 8.22(3n) | Fe II .16(3) (Eu II .19(8)) (Zr II .05(12)) |
| 4258.58(0) | | | | | Eu II .50(8) Ti I .54(70) |
| | 8.84(0) | | 8.86(0) | 8.96(1) | |
| 4259.23(3n) | 9.27(2n) | 9.20(3) | 9.31(6) | 9.36(3n) | Mn II .26(2) A I .36(1200) (Eu II .22(3)) |
| 4259.50(2n) | 9.46(1) | | | | |
| 4259.78(0) | | 9.87(0) | 9.76(0) | 9.83(1) | Ce II .75(15) (Nd II .61(4)) |
| 4260.08(0) | | | 0.02(0) | 0.21(1) | (Eu II .99(2)) |
| 4260.40(3) | 0.51(3) | 0.43(2) | 0.48(2) | 0.50(2) | Fe I .48(400) |
| 4260.92(1) | 1.00(1) | | | | Eu II .98(5) |
| 4261.25(0) | | 1.17(1) | 1.16(2n) | 1.26(1) | Ce II .16(18) (Cr I .35(125)) (Eu II .16(3)) |
| | 1.44(0) | | 1.50(1) | 1.66(0) | Ti I .60(70) |
| 4261.83(5) | 1.92(8) | 1.92(8) | 1.97(9) | 2.01(7) | Cr II .91(20) Gd II .09(2500) (Nd II .84(20)) (Pr II .80(15)) |
| 4262.12(1n) | | | | | Gd II .09(2500) (Nd II .24(4)) (Pr II .31(10)) |
| 4262.59(0) | 2.57(1) | 2.77(1n) | 2.46(0) | 2.77(1) | Sm II .68(300) |
| 4263.07(1n) | 3.06(1) | 3.14(0) | 3.22(1n) | 3.29(1) | Ti I .13(125) Cr I .14(125) Ce II .43(40?) (Nd II .44(10)) |
| 4263.77(2) | 3.86(3) | 3.81(2) | 3.89(3) | 3.97(2n) | Fe II .90(1) (Eu II .80(5?)) (Pr II .80(30)) (Gd II .01(5)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4264.36(1) | 4.41(1) | 4.51(1) | | | Ce II .37(10?) |
| 4264.94(0) | 4.79(0) | 4.60(0) | 4.61(1) | 4.67(1) | (Eu II .91(3)) (Zr II .91(4)) |
| | | 5.16(0) | 5.24(0) | 5.23(0) | Sm II .08(100) Cr II .04(0) |
| | 5.42(0) | | | 5.68(0) | |
| 4265.81(1n) | 5.90(1) | 5.83(0) | 6.02(0) | 5.93(0) | Mn I .92(100) (Eu II .81(4)) (Dy II .83(1)) |
| | 6.16(0) | 6.35(0) | 6.35(1) | 6.42(2) | A I .29(1200) (Cr II .23(pr)) (Eu II .38(4?)) |
| 4266.64(1) | 6.80(0) | 7.00(0) | 6.97(0) | 6.92(1) | Fe I .97(70) Nd II .72(30) (C II .02(350)) (Zr II .72(1)) |
| 4267.21(1) | 7.25(0) | | 7.23(0) | 7.33(1) | C II .27(500) |
| 4268.14(0n) | 8.09(0) | 8.05(0) | 7.90(0n) | 7.93(1) | Ce II .16(500) Fe I .83(125) |
| | 8.54(0) | | | 8.58(0) | Eu II .44(3) |
| 4268.73(3) | 8.84(2) | 8.94(1) | 8.87(1) | | Cr II .93(1) Gd II .73(150) (Pr II .100(10)) |
| 4269.16(4) | 9.32(4) | 9.30(4) | 9.34(4) | 9.38(3) | Cr II .28(10) |
| 4269.34(0) | | | | | La II .50(300) |
| 4269.99(0n) | 0.01(1n) | 0.06(1) | 0.08(0) | 0.04(0) | Eu II .24(10) Ce II .19(60) (Ti I .14(30)) |
| 4270.64(4) | 0.67(1) | | 0.47(1n) | 0.52(3n) | Eu II .50(12?) Eu II .24(10) Nd II .56(25) |
| | | | 0.74(1n) | 0.85(2) | Ce II .72(50) |
| 4271.02(3) | 1.22(2) | 1.21(1) | 1.19(1) | | Fe I .16(400) |
| | | | 1.36(1) | 1.42(1) | |
| 4271.67(3) | 1.81(3) | 1.71(2n) | 1.85(4) | 1.88(3) | Fe I .76(1000) (Pr II .76(15)) |
| 4272.13(1n) | 2.08(1) | 2.17(1) | 2.24(3) | 2.34(2) | Pr II .27(80) (A I .17(1200)) (Eu II .11(4)) |
| 4272.56(0) | 2.51(0) | 2.62(0) | 2.61(0) | | Ti I .43(40) (Eu II .76(3)) (Nd II .79(30)) |
| 4272.82(0) | | | 2.91(1) | 2.94(0) | Eu II .76(3) Nd II .79(30) |
| | | | | 3.04(1) | Eu II .06(4) (Dy II .14(2)) (Tb II .19(3)) |
| 4273.24(6) | 3.32(6) | 3.29(5) | 3.36(6) | 3.42(4) | Fe II .32(3) |
| 4273.62(1) | | | | | Zr II .52(4) |
| 4274.06(1) | 3.91(0) | 4.09(1) | 3.84(1) | 3.89(1) | |
| | | | 4.30(0) | 4.40(0) | |
| 4274.59(3) | 4.66(2n) | | 4.60(1) | | Ti I .58(100) |
| 4274.93(1) | 4.98(1) | 4.87(2n) | 4.90(1n) | 5.01(0) | Cr I .80(4000) Eu II .86(5) (Nd II .08(10)) (Gd II .03(4)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4275.43(5) | 5.56(4) | 5.57(3) | 5.62(4) | 5.66(2) | Cr II .57(30) (La II .64(100)) (Ce II .56(25)) |
| 4276.15(0) | 5.97(1) | 6.18(0) | 6.28(1) | 6.31(1) | Eu II .20(30) (Tb II .14(2)) (Ti I .43(50)) |
| 4276.61(1) | 6.59(1n) | 6.54(0) | 6.86(0) | | (Tb II .75(15)) (Ti I .43(50)) |
| 4276.96(0) | 7.17(0) | | | 7.13(0) | (Nd II .28(6)) |
| 4277.44(1) | 7.47(1) | 7.42(1) | 7.45(2) | 7.45(1) | (Zr II .37(4)) (Nd II .28(6)) |
| 4278.07(2) | 8.13(3n) | 8.08(3) | 8.20(4) | 8.24(3n) | Fe II .13(1) Cr II .10(1) |
| 4278.62(0) | 8.68(0) | 8.69(1) | 8.73(1) | 8.80(1) | Tb II .54(200) Ce II .87(20) (S II .54(30)) (Cr II .94(pr)) |
| 4279.34(0) | | | 9.46(0) | | |
| 4279.71(0) | 9.64(0) | 9.78(1) | | 9.66(0) | Sm II .68(200) |
| 4279.97(1) | | 0.24(1) | 0.03(2) | 0.23(0) | Ce II .14(15?) Pr II .10(30) |
| 4280.46(1) | 0.33(1n) | | 0.44(2) | 0.50(2n) | Gd II .49(1500) Sm II .79(400) (Eu II .36(8)) (Cr II .33(pr)) |
| 4280.98(1) | 1.05(1n) | 1.00(0) | 1.01(1) | | Sm II .01(100) (Cr II .03(pr)) (Mn I .10(100)) |
| 4281.62(1) | 1.59(1) | 1.60(0) | 1.37(1) | 1.37(1) | Ti I .38(80) |
| 4281.87(0) | 1.88(1) | 1.80(0) | 2.04(1n) | 2.02(0) | Eu II .92(8) |
| 4282.36(4) | 2.48(2) | 2.42(1) | 2.44(3) | 2.47(1n) | Fe I .41(600) Mn II .50(3) Pr II .44 (60) (Nd II .57(15)) (Nd II .44(50)) (Zr II .21(6)) |
| 4282.95(1) | 3.04(1) | 3.00(0) | 3.29(1) | 3.18(0) | Cr II .02(1) (Gd II .79(50)) |
| 4283.56(0) | 3.51(0) | 3.75(0) | 3.76(1) | 3.74(0) | Mn II .81(1) (Eu II .87(4)) |
| 4284.09(2) | 4.15(2) | 4.25(4) | 4.32(6) | 4.40(3n) | Cr II .21(20) (Mn I .08(40)) |
| 4284.48(1) | 4.47(1) | | | | Nd II .52(100) (Mn II .42(0)) (Gd II .57(5)) |
| 4285.35(1) | 5.40(1) | 5.30(1n) | 5.32(1n) | 5.38(2n) | Fe I .44(125) Ce II .37(30) (Eu II .34(4)) |
| 4285.62(1) | | 5.58(0) | | 5.74(0) | Sm II .50(200) (Tb II .74(5)) |
| 4286.16(3) | 6.19(3n) | 6.23(2) | 6.32(3) | 6.36(2) | Fe II .31(1) Ti I .01(100) Cr II .36(1) |
| 4286.63(1) | | | | | Sm II .64(100) (Eu II .70(4)) (Zr II .51(5)) |
| 4287.05(1) | 6.98(1) | 7.02(1n) | 7.06(1) | 7.20(1) | La II .97(300) (Tb II .89(8)) |
| 4287.81(2) | 7.92(3) | 7.75(1n) | 7.79(1) | 7.89(2) | Ti II .88(30) |
| 4288.44(3) | 8.43(2n) | 8.43(2n) | 8.34(2n) | 8.38(1) | P II .52(50) (Eu II .60(2)) |
| 4289.05(1) | 9.09(1) | 9.24(0) | 8.94(0) | 9.18(0) | Ti I .07(125) (Zr II .18(2)) |
| 4289.35(1) | | | | | Ce II .45(25) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4289.59(1) | 9.62(1) | 9.65(1) | | | Cr I .72(3000) Ce II .45(25) |
| 4290.19(x) | 0.20(4n) | 0.07(2n) | 9.99(6n) | 0.02(5) | Ce II .94(300) Gd II .88(80) (Ti II .23(60)) |
| 4290.92(1n) | 0.94(1n) | 0.89(1) | 0.90(1) | 0.94(1) | Nd II .96(6) |
| 4291.63(1n) | 1.80(1) | 1.61(0) | 1.67(1n) | 1.64(1) | Fe I .47(125) |
| 4292.16(0) | 2.23(1) | 2.25(1) | 2.28(1) | 2.40(1) | Sm II .18(150) Mn II .25(2) (Eu II .95 (5)) (Eu II .44(6)) (Gd II .31(5)) |
| 4292.80(1) | | | | | Gd II .75(25) Ce II .77(4) (Tb II .63(2)) |
| 4293.13(2) | 3.04(1n) | 2.96(1) | 2.91(2) | 2.99(2n) | Pr II .14(15) Zr II .14(7) |
| 4293.52(0) | 3.71(0) | | 3.50(0) | | Pr II .58(20) |
| 4294.07(4) | 4.14(3) | 4.05(2) | 4.04(2) | 4.09(3) | Ti II .12(80) Fe I .13(700) (Ti I .12(60)) |
| 4294.72(0) | 4.79(1) | 4.79(0) | 4.81(1) | 4.83(2) | Pr II .70(20) Dy II .94(60) Eu II .54(3) Eu II .70(3) |
| 4295.11(3) | 5.17(2) | 5.41(0) | 5.34(1) | 5.43(2) | Dy II .94(60) Eu II .44(15) (Cr II .37(pr)) |
| 4295.62(1) | 5.65(0) | 5.87(1) | | | Ti I .76(100) Cr I .76(125) |
| 4296.09(0) | | | 6.07(2) | 6.15(1) | Gd II .08(1000) La II .05(300) Ce II .07(6) |
| 4296.48(4) | 6.49(4n) | 6.56(9) | 6.62(8) | 6.68(3) | Fe II .57(6) Gd II .30(400) |
| 4296.78(1) | 6.86(1) | | | | Ce II .68(200) (Ce II .79(5)) (Gd II .17(400)) |
| 4297.30(1) | 7.31(1) | 7.19(1) | 7.13(1) | 7.25(1) | Gd II .17(400) Cr I .05(100) (Nd II .35(8)) |
| | 7.58(1) | 7.63(1) | 7.62(0) | 7.58(0) | |
| 4297.85(0) | 7.80(1) | | 7.74(0) | | Pr II .76(80) Cr I .74(125) (Nd II .80(30)) |
| | 8.07(0) | 8.20(0) | 8.20(1) | 8.29(1n) | Fe I .04(100) |
| 4298.52(0) | 8.41(1) | | | | Gd II .43(30) Ti I .66(125) |
| | 9.04(1) | | 8.86(1n) | | Pr II .92(15) |
| 4299.19(1n) | 9.29(1) | 9.21(1) | 9.26(2n) | 9.21(2) | Fe I .24(500) Ce II .36(60) (F II .18(150)) |
| | 9.78(1) | | 9.84(2) | | Cr I .72(100) Nd II .70(10) |
| 4300.03(4n) | 0.07(3) | 0.09(3) | 9.97(5) | 0.02(4) | Ti II .05(100) (A I .10(1200)) |
| 4300.24(1n) | | | | | Ce II .33(60) (Mn II .20(1)) |
| 4300.61(0) | 0.73(1n) | 0.53(1) | 0.44(0n) | 0.53(1) | Ce II .33(60) La II .44(60) Cr I .51(100) Ti I .56(125) (Dy II .76(1)) (Dy II .41(1)) |
| 4301.38(0) | 1.42(1) | 1.30(1) | 1.27(0n) | 1.38(1) | V II .13(40) (Cr I .18(100)) (Eu II .58(6)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4301.85(5) | 1.97(3) | 1.81(2) | 1.86(3n) | 1.87(3n) | Ti II .93(50) (Pr II .10(60)) (Zr II .81(5)) |
| 4302.58(0) | 2.48(1) | | 2.56(0) | 2.44(1) | Cr II .58(1) (Dy II .57(4)) |
| 4303.13(6) | 3.12(6) | 3.14(7) | 3.20(6n) | 3.26(2) | Fe II .17(8) |
| 4303.64(0) | 3.68(1) | 3.65(1) | 3.52(0n) | 3.61(0) | Gd II .47(25) Nd II .57(400) |
| 4304.19(0) | 4.12(1) | 4.00(0) | 4.11(0) | 4.05(0) | Gd II .09(25) (La II .11(10)) |
| 4304.78(0) | 4.95(1) | 4.94(0n) | 4.74(1n) | 4.80(1) | Gd II .90(400) |
| 4305.45(0) | 5.52(0) | | 5.64(1n) | 5.70(1) | Fe I .46(100) Pr II .76(100) (Cr I .45(150)) |
| 4306.01(1) | 6.10(1) | | | 6.17(1) | Pr II .08(30) Ti I .92(300) |
| 4306.40(1) | | | | | Eu II .38(4) |
| 4306.90(4n) | 6.91(4) | 6.91(2) | 6.80(3) | 6.81(4) | Cr II .95(5) |
| 4307.36(0) | 7.63(1) | | | 7.46(0) | |
| | | | | 7.77(2) | Ti II .90(100) |
| 4307.82(4) | 7.90(4) | 7.86(4) | 7.86(4) | | Fe I .91(1000) Ti II .91(100) (Gd II .87(40)) (Nd II .78(15)) |
| | | | | 8.00(4) | Fe I .91(1000) |
| | 8.30(1) | | 8.36(1) | 8.42(2) | Gd II .23(40) |
| 4308.66(1) | 8.82(2) | 8.88(0) | 8.86(2) | 8.89(2) | Dy II .62(200) Cr II .82(2) (Tb II .68 (25)) (Eu II .83(3)) (Zr II .94(4)) |
| 4309.06(0) | 9.10(0) | | | | Sm II .01(200) (K II .08(40)) (Cl II .06(50)) |
| | | | | 9.42(0) | Fe I .38(125) |
| 4309.71(1) | 9.68(2n) | 9.61(1n) | 9.65(1) | 9.72(1) | Cr II .75(3) Ce II .74(50) (Y II .63(50)) |
| | 0.45(2) | | | | Nd II .51(6) |
| | 0.75(0) | 0.80(0n) | | | Ce II .70(30?) (Eu II .60(2)) |
| | | | 0.90(2) | 0.94(1) | Gd II .98(200) (Eu II .02(5)) (Tb II .99(8)) |
| 4311.18(1) | 1.13(1) | | | 1.31(1) | Eu II .28(3) (Pr II .10(10)) |
| 4311.54(0) | 1.68(1) | | | | |
| 4312.04(1) | 2.21(1) | 1.92(0n) | 1.94(3) | 2.14(1) | Tb II .09(8) (Zr II .23(3)) |
| 4312.84(4) | 2.92(5) | 2.89(4n) | 2.90(5) | 2.92(4n) | Ti II .87(100) (Fe II .03(1)) |
| 4313.82(1) | 3.74(1) | | 3.68(3) | 3.65(3) | Eu II .85(5) (Dy II .89(2)) |
| 4314.30(1n) | 4.25(2) | 4.27(3) | 4.33(4) | 4.38(3) | Fe II .29(4) (Nd II .37(8)) (Gd II .28(10)) (Nd II .51(5)) |
| 4314.89(3) | 5.02(3) | 4.89(2) | 4.93(4) | 4.97(4) | Ti II .98(20) Fe I .09(500) (Ti I .80(100)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4315.27(1) | | 5.01(1) | | | Fe I .09(500) |
| | 5.43(1) | 5.57(1) | 5.50(1) | 5.53(1) | |
| 4316.01(1n) | 6.15(0n) | 6.02(0) | 6.04(1) | 6.11(1) | Gd II .05(600) Gd II .27(150) (La II .90(30)) |
| 4316.77(2) | 6.92(2) | 6.67(0) | 6.68(1) | 6.66(0) | Ti II .80(35) (Yb II .97(10)) |
| 4317.23(0) | | 6.97(0) | 7.26(1n) | 7.21(0) | Zr II .32(12) (O II .16(150)) |
| 4317.73(1) | 7.83(1) | 7.77(0n) | 7.59(0) | 7.64(1) | Eu II .67(8) (Pr II .84(10)) |
| 4318.05(1) | 8.24(1) | 8.10(1) | 8.18(0) | 8.30(1) | Fe II .22(0n) |
| | 8.72(1) | 8.81(0) | 8.74(0) | 8.72(1) | Cr II .77(pr) |
| | | 8.95(0) | | 9.08(1) | Sm II .94(500) (Pr II .00(10)) |
| 4319.58(2) | 9.56(3n) | 9.54(2) | 9.54(2n) | 9.75(2) | Fe II .72(1n) (Cr I .64(100)) (O II .65(150)) |
| 4320.21(0) | 0.11(1) | 0.24(0) | | 0.35(1n) | (Eu II .16(2)) |
| 4320.81(2) | 0.84(2n) | 0.75(1) | 0.74(2n) | 0.92(1) | Ti II .96(40) Ce II .72(60) (Sc II .74(40)) (Cr I .59(125)) |
| 4321.19(2) | 1.32(1) | 1.23(1) | | 1.40(1) | Gd II .11(200) Fe II .34(1n) |
| | | 1.60(0) | | 1.77(1) | Ti I .66(70) (Eu II .67(3)) |
| 4321.95(1) | 2.06(1n) | | 1.97(0) | 2.18(0) | Gd II .20(125) (Eu II .87(4)) (Dy II .19(1)) |
| 4323.09(1) | 3.13(1n) | | 2.91(1) | 2.89(1) | (Sm II .28(200)) |
| | 3.80(0) | | 3.78(0) | 3.62(0) | Pr II .55(25) (Tb II .65(15)) (Zr II .62(2)) |
| 4324.00(1n) | | | | | Gd II .06(150) (Nd II .90(2)) |
| | | | 4.34(0) | 4.36(0) | Eu II .31(4) |
| 4324.75(1) | 4.91(1) | 4.97(1) | 4.91(1) | 4.98(2) | (Dy II .14(40)) |
| 4325.64(4) | 5.57(4n) | 5.58(4n) | 5.55(5) | 5.58(5) | Fe I .76(1000) Gd II .57(200) (Nd II .77(150)) (Tb II .82(60)) (Zr II .64(3) |
| | 6.16(0) | | | 6.13(1) | Eu II .13(4) |
| 4326.38(1) | | | | | Gd II .32(20) |
| 4326.54(1) | 6.60(2) | 6.65(1) | 6.62(1n) | 6.61(1) | (Mn II .71(3)) (Ce II .83(15)) |
| 4327.08(1) | 7.19(0) | | | 7.11(0) | Gd II .12(1500) Fe I .10(100) |
| 4327.93(1n) | 8.15(0) | | 7.84(1) | 7.84(1n) | Nd II .93(30) (Tb II .08(1)) |
| 4328.96(1) | 9.04(0) | | 8.72(0n) | 8.83(2) | Dy II .90(20) Sm II .02(400) (Cr II .91(pr)) (Pr II .98(20)) |
| 4329.59(0) | | | | 9.43(0) | Pr II .42(25) |
| | | | | 9.76(1) | (Dy II .89(1)) |
| 4330.19(0) | 0.30(1n) | 0.27(0) | 0.25(1) | 0.12(0) | Ti II .24(40) Gd II .32(20) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4330.50(3n) | 0.73(1n) | | 0.51(2n) | 0.46(2n) | Gd II .61(600) Ti II .71(30) Eu II .61(40) Ce II .44(30) |
| 4331.47(0) | | | | | Fe II .53(3) |
| | 1.70(0) | | 1.68(0) | 1.62(1) | (Ni I .64(200)) |
| 4332.55(0) | | | | 2.52(0n) | Cr I .57(125) (Eu II .40(2)) |
| | 2.80(0) | | | 2.76(0) | (Eu II .85(3)) |
| 4333.42(0) | | | | 3.35(1n) | Zr II .28(15) (A I .56(1000)) |
| 4334.20(1) | | | 4.05(0) | 3.98(1) | Sm II .15(400) Pr II .91(100) La II .76(500) (Eu II .16(6)) |
| | | 4.63(0) | | 4.62(0) | Pr II .62(15) |
| 4334.88(0) | | | | | La II .96(100) Eu II .75(12) |
| 4336.34(0) | | | 6.24(0) | 6.37(1) | Ce II .26(50) Eu II .44(6) (Cl II .26(45)) |
| 4337.12(0) | | | | 7.04(0) | Fe I .05(400) (Ho II .13(4)) |
| 4337.84(1) | 7.91(0) | 7.84(1) | | 7.97(1n) | Ti II .92(125) Ce II .78(125) (La II .78(10)) (Zr II .63(5)) |
| 4338.65(0) | | | 8.62(0) | | Nd II .70(80) Pr II .69(25) (Fe II .70(pr)) |
| 4339.23(0) | | | | 9.35(0) | Ce II .32(30) (Cr I .45(300), |
| 4340.43(xn) | 0.44(xn) | 0.45(xn) | 0.45(xn) | 0.46(xn) | H γ .48(200) |
| | | | | 1.54(1) | Gd II .28(600) (Ti II .38(40)) |
| 4341.74(0) | | 1.73(0) | | 1.77(0) | |
| | | | | 2.24(0) | Gd II .18(1500) Fe II .36(0) (Nd II .07(20)) |
| 4342.66(0) | | | 2.64(0) | | Tb II .50(30) |
| 4343.18(1) | | 3.16(0) | | 3.32(0) | |
| 4344.12(1n) | 3.98(1) | 4.03(1) | 4.09(2) | 4.07(0n) | Gd II .30(100) Ti II .29(50) Mn II .99(2) Pr II .33(40) (Tb II .20(3)) |
| 4344.63(0) | | 4.52(0) | | 4.64(0) | Gd II .49(40) Cr I .51(400) |
| | | 5.37(0) | 5.13(0) | 5.15(0) | A I .17(1000) |
| 4345.57(0) | | 5.66(1) | | 5.65(1) | (O II .57(125)) (Mn II .60(pr)?) |
| 4346.38(1n) | 6.42(1n) | 6.37(0) | 6.33(0) | 6.38(1) | (Dy II .33(1)) |
| 4347.34(1n) | | 7.41(1) | 7.40(1) | 7.52(1) | Gd II .31(400) (Pr II .49(30)) |
| 4347.79(1) | | | | | Sm II .80(400) Al II .78(20) (Al II .80(18)) (A II .11(500)) |
| 4348.53(1n) | 8.34(0) | 8.66(0) | | 8.30(0) | Mn II .49(1) (Tb II .34(3)) |
| 4349.08(1) | | | | 8.97(0) | |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4349.46(0) | 9.56(0) | | 9.54(0) | | (O II .44(300)) (Eu II .49(2)) |
| 4349.80(1) | 9.91(0) | 9.64(0) | 9.73(0) | 9.75(0) | Ce II .79(100) |
| 4350.35(1) | 0.39(1) | 0.63(1) | 0.53(0) | | Sm II .46(300) Pr II .40(20) (Eu II .42(2)) |
| 4350.75(2) | 0.92(1) | 0.97(1) | 0.77(0) | 0.69(0) | Ti II .83(30) (Cr I .05(100)) |
| 4351.23(0) | | | | 1.45(0) | Eu II .26(4) Nd II .30(40) (O II .28(125)) (Nd II .18(15)) |
| 4351.67(7) | 1.73(7) | 1.75(9) | 1.82(9) | 1.88(8) | Fe II .76(9) (Cr I .77(300)) (Pr II .85(50)) (Tb II .57(8)) |
| 4351.96(0) | | | | | Mg I .91(15) Sm II .10(200) |
| 4352.53(2) | 2.60(2) | 2.56(3) | 2.63(3) | 2.67(2n) | Fe I .74(300) Ce II .73(75) (Eu II .24(6)) (Gd II .67(15)) |
| 4353.35(1) | 3.36(1) | 3.29(1n) | 3.41(0) | 3.43(1n) | Tb II .19(50) (Eu II .51(2)) |
| | 3.71(0) | 3.87(0) | | | |
| 4354.24(3) | 4.34(2) | 4.26(2) | 4.26(1) | 4.30(2) | Fe II .36(2) (Gd II .06(40)) |
| 4354.95(1) | 5.02(0) | 4.90(0) | 4.97(1n) | 5.17(3n) | (Pr II .91(15)) |
| 4355.36(6) | 5.40(3) | 5.36(1) | 5.40(1n) | | Eu II .09(300) (Nd II .35(2)) |
| 4355.71(0) | 5.50(1) | | 5.53(1) | 5.62(1) | |
| 4356.04(1) | 6.08(0) | | 6.14(1) | | (Nd II .02(10)) |
| | | 6.38(1n) | 6.33(1) | 6.42(3) | |
| 4356.61(3) | 6.69(2) | 6.79(1n) | 6.78(0) | | Gd II .74(10) |
| | 7.03(1) | | 6.98(0) | 7.15(1) | |
| 4357.45(5) | 7.57(3) | 7.53(3) | 7.56(3) | 7.67(2) | Fe II .57(4) |
| 4358.17(1) | 8.22(1) | 8.24(1) | 8.20(2) | 8.28(1) | Nd II .17(200) |
| 4358.54(1) | 8.57(0) | | 8.79(1) | 8.65(0) | Dy II .46(60) Fe I .50(70) (Nd II .70(15)) |
| 4358.94(0) | | 8.93(1) | | | |
| 4359.14(0) | 9.04(0) | 9.13(0) | 9.00(0) | 9.08(1) | Pr II .11(15) Gd II .15(40) (Nd II .24(5)) |
| 4359.73(2) | 9.71(1n) | 9.63(0) | 9.55(1) | 9.64(0) | Gd II .64(30) Pr II .80(30) (Zr II .74(10)) (Cr I .63(200)) (Ni I .58(100)) |
| 4360.28(1) | 0.21(1) | 0.35(1n) | 9.99(0) | 9.95(1) | Ce II .16(25?) |
| | 0.66(0) | | 0.75(0) | 0.64(1) | Sm II .72(150) (Nd II .82(2)) |
| 4361.15(4n) | 1.26(3) | 1.20(4n) | 1.26(4) | 1.29(3) | Fe II .25(2) Gd II .92(250) |
| 4361.45(1) | | | | | Eu II .57(8) (Dy II .39(2)) |
| 4361.96(2n) | 2.09(1) | 1.99(1) | 1.92(1) | 1.94(2n) | Sm II .04(300) Ni II .10(1) Ce II .66(18) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4362.21(1) | 2.38(0) | 2.31(0) | | 2.37(1n) | (Eu II .43(2)) (Gd II .30(4)) |
| 4362.82(2) | 2.97(2) | 2.87(1) | 2.97(2) | 2.95(1) | Cr II .93(3) (Pr II .98(10)) (La II .05(50)) |
| 4363.51(3n) | 3.61(1) | 3.62(0) | 3.34(2) | 3.39(4) | Mo II .64(200) (Pr II .22(10)) |
| 4364.21(1) | 4.26(1) | | 4.00(1) | 4.07(2) | Gd II .14(25) Dy II .28(40) Nd II .14(10) Dy II .06(2) (Ho II .18(3)) |
| 4364.63(1) | 4.80(1) | 4.57(0) | 4.65(1) | 4.76(1) | Ce II .66(125) (La II .66(100)) |
| 4365.09(1) | | | | | (Eu II .18(2)) |
| 4365.62(1) | 5.54(0) | | 5.32(0) | 5.40(1) | |
| 4366.15(2) | 6.15(1) | 5.97(0) | 5.97(2n) | 6.06(1n) | Fe II .16(tr) (Nd II .32(12)) (Nd II .39(8)) (Tb II .01(3)) |
| 4367.01(1) | 7.07(0) | 6.76(1) | 6.79(1) | 6.84(1) | (O II .91(100)) |
| | 7.37(0) | | | 7.54(0n) | Gd II .31(15) |
| 4367.60(3) | 7.75(2) | 7.52(1) | 7.60(2) | 7.74(2n) | Ti II .66(25) Fe I .58(100) (Eu II .54(3)) |
| 4368.01(2) | 8.14(2) | 8.01(1) | | | Fe I .91(60) Sm II .03(150) (Eu II .89(2)) (Gd II .03(4)) |
| 4368.30(0) | | 8.36(1) | 8.24(2) | 8.36(1) | Fe II .26(1) Pr II .33(150) (O I .30(1000)) (Ce II .23(87)) (Eu II .42(8)) |
| 4368.72(0) | 8.66(0) | | | 8.80(0) | Nd II .63(60) |
| 4369.28(3) | 9.34(3n) | 9.39(4n) | 9.48(5n) | 9.53(3n) | Fe II .40(2) Eu II .47(40) (Cl I .52(12)) |
| 4369.56(1) | | | | | Eu II .47(40) |
| 4369.78(1n) | 9.79(1n) | | | 9.87(0) | Fe I .77(200) Gd II .77(500) (Ne II .77(70)) |
| 4370.40(0) | | 0.38(1) | 0.44(1) | 0.23(0) | Eu II .34(20) |
| 4370.97(2n) | 0.88(1) | 0.95(1n) | 0.96(1) | 0.81(3) | Pr II .80(8) Zr II .96(8) (Tb II .93(3)) (Nd II .07(10)) |
| | 1.06(2n) | | | | Nd II .07(10) |
| | | | | 1.71(1) | Pr II .61(40) |
| 4371.89(3n) | 1.99(1n) | 1.93(1n) | 1.90(0) | 1.90(1) | |
| 4372.30(1n) | 2.34(1) | | 2.22(0) | 2.27(1) | Ce II .40(35?) Eu II .20(8) (Nd II .28(8)) (Nd II .14(3)) |
| 4372.92(1) | 3.05(1) | 2.87(0) | 2.92(0) | 2.86(1) | (Nd II .73(4)) |
| 4373.47(1) | 3.59(1) | 3.58(1) | 3.57(1) | 3.52(1) | Fe I .57(50) Sm II .46(100) (Eu II .45(3)) |
| 4373.79(0) | | | | 3.87(0) | Ce II .82(50) Pr II .82(10) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4374.28(1) | 4.31(1) | | | 4.18(1) | Dy II .24(125) Gd II .24(30) (Pr II .41(20)) (Sc II .46(25)) (Cr I .16(50)) |
| 4374.78(3) | 4.90(2) | 4.91(2) | 4.66(2) | 4.70(3) | Ti II .82(35) Dy II .80(100) Sm II .98(200) (Y II .94(150)) (Mn I .95(150)) (Nd II .04(30)) (Nd II .92(20)) |
| 4375.31(1) | 5.28(0) | | 5.09(2) | 5.18(2) | Dy II .33(50) Eu II .12(5) |
| 4375.94(1) | 5.94(1) | 5.85(1) | 6.05(0n) | 5.99(1n) | Fe I .93(500) Ce II .92(60) |
| 4376.31(1) | 6.34(1) | | 6.32(0) | 6.25(0) | (Eu II .42(3)) (Nd II .44(3)) (Tb II .44(5)) |
| 4377.08(2n) | 7.13(2n) | 7.12(1n) | 7.10(1n) | 7.14(1n) | (Nd II .10(5)) (Nd II .40(4)) |
| 4377.70(0) | 7.77(0) | | | 7.56(0) | Mo II .76(200) |
| 4378.20(1) | 8.29(1) | 8.02(0) | 8.00(1) | 8.03(2) | Sm II .24(150) Cr II .34(1) (La II 10(50)) (Eu II .27(1)) |
| 4379.01(1) | | | 8.86(0) | 8.93(1) | (Tb II .73(4)) |
| 4379.79(1n) | 9.82(1) | 9.55(1) | 9.59(1n) | 9.80(2) | Zr II .78(9) Mn II .74(1) (Eu II .81(5)) (Cl I .91(15)) |
| 4380.72(1) | 0.71(1) | 0.61(0) | 0.51(1) | 0.65(2n) | Gd II .64(100) (Pr II .32(12)) |
| 4381.18(0) | | | 1.39(1) | 1.44(1) | Nd II .29(10?) |
| 4381.67(2) | 1.66(1) | 1.62(0) | | | Mn I .70(80) |
| 4382.21(2) | | 2.13(0) | 2.04(0) | 2.05(1) | Gd II .06(60) Ce II .17(200) (Eu II .05(4)) |
| 4382.41(1) | 2.50(2n) | 2.56(1n) | 2.55(2) | 2.68(1) | Cr II .53(1) Pr II .42(20) (Nd II .74(15)) (Mn I .63(80)) |
| 4382.99(1) | 2.93(0) | 3.00(0) | 2.99(0) | 3.09(1) | Gd II .12(150) Eu II .17(200) (Pr II .82(20)) (Zr II .95(1)) |
| 4383.42(5) | 3.48(4) | 3.51(3) | 3.59(3) | 3.77(2n) | Fe I .55(1000) (La II .44(100)) |
| 4384.11(7) | 4.19(5) | 4.23(4n) | 4.22(3) | 4.23(2n) | (Pr II .14(20)) (Dy II .30(2)) (Tb II .06(5)) |
| 4384.50(0) | 4.62(1) | 4.78(0) | 4.77(1) | 4.47(1) | Mg II .64(8) |
| | | | | 4.83(0) | (Cr I .98(150)) (Er (II?) .70(85)) |
| 4385.31(9) | 5.34(7) | 5.36(9) | 5.39(6) | 5.44(5) | Fe II .38(7) (Nd II .66(150)) (Dy II .29(2)) (La II .20(40)) |
| 4386.09(1) | 6.05(1) | | | 5.90(1) | Tb II .09(10) |
| 4386.53(1n) | 6.53(1n) | 6.27(0) | 6.24(1) | 6.30(1) | |
| 4386.80(6n) | 6.96(3) | 6.74(1n) | 6.74(4) | 6.76(4) | Ti II .85(80) (Ce II .84(15)) |
| | 7.30(1) | 7.03(1) | | | |
| 4387.66(1) | 7.72(1) | 7.72(0n) | 7.54(1) | 7.56(2) | Gd II .67(300) Fe I .90(150) |
| 4388.23(2) | 8.28(1n) | | 8.03(2) | 8.12(3) | Ce II .01(8) Fe I .41(125) (K II .13(40)) |

Table 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| | | | 8.69(0) | 8.67(1) | (Zr II .50(2)) |
| 4388.94(1n) | 9.01(1n) | 8.98(0) | | 9.04(1) | Gd II .98(15) (Eu II .07(4)) (Tb II .04(3)) |
| 4389.71(1n) | | 9.40(0) | 9.50(0n) | 9.61(1) | Fe II .40(1) (Gd II .69(6)) |
| | 9.86(0) | | | 9.94(0) | Gd II .00(10) (Cl I .76(25)) |
| 4390.47(3) | 0.54(1) | 0.44(0) | 0.26(1n) | 0.34(3) | Nd II .66(20) Mg II .58(10) (Eu II .36(3)) |
| 4391.04(3) | 1.15(1) | | 0.86(1n) | 0.90(2n) | Gd II .95(300) Ti II .03(25) Sm II .86(600) Fe I .95(100) (Nd II .11(10)) |
| 4391.64(4) | 1.76(2) | 1.70(1) | 1.62(1n) | 1.69(1n) | Ce II .66(250) Gd II .44(15) (Eu II .37(10)) (S II .84(30)) |
| 4392.16(1) | 2.15(0) | | | 1.94(0) | (Ne II .94(150)) (Gd (?) .07(100)) |
| 4392.56(1) | 2.54(1) | 2.58(0) | 2.59(0) | 2.42(0) | |
| 4393.10(2) | 3.18(1) | 3.05(0) | | 2.92(2) | |
| | | | 3.32(1n) | 3.40(2) | |
| 4393.62(2) | 3.72(1) | | | | |
| 4394.02(3) | 4.15(2) | 4.09(1) | 3.91(2) | 3.96(1) | Ti II .06(15) (Ti I .92(60)) (Nd II .20(2)) |
| 4394.39(1) | | | | 4.36(0) | |
| 4395.06(6) | 5.10(3) | 5.01(2n) | 4.94(4n) | 4.96(5n) | Ti II .04(150) Fe I .29(80) Dy II .98(40) (Pr II .00(15)) (Tb II .92(3)) |
| 4395.76(5) | 5.84(3) | 5.77(2n) | 5.78(4n) | 5.82(4) | Ti II .84(30) Pr II .79(30) |
| | | | | 6.26(0) | Pr II .12(40) |
| 4396.57(0) | 6.45(1) | | 6.54(1) | | |
| 4397.10(0) | 6.89(1) | 6.92(1) | 6.81(1) | 6.73(1) | |
| 4397.59(0) | | | 7.38(1) | 7.41(1) | Gd II .51(300) |
| 4397.88(0) | 7.88(0n) | | | | Y II .01(100) Eu II .70(8) (Ne II .94(100)) (Nd II .67(3)) |
| 4398.25(3) | 8.29(1) | 8.06(1n) | 8.10(2n) | 8.08(2) | Ti II .31(10) Y II .01(100) |
| | | 8.61(0) | | 8.51(1) | |
| 4398.78(0) | 8.87(1) | | | 8.98(1) | Ce II .79(20?) |
| 4399.14(1) | 9.31(1) | 9.05(1) | 9.08(1n) | 9.19(1) | Eu II .32(15) Ce II .20(60) (Pr II .33(15)) (Zr II .44(2)) |
| 4399.71(4) | 9.85(3) | 9.82(2) | 9.66(2) | 9.72(2n) | Ti II .77(100) |
| 4400.13(1) | 0.25(1) | | 0.31(0) | 0.24(0) | Gd II .18(25) (Pr II .03(15)) (Dy II .10(1)) (Sc II .36(30)) (Pr II .25(10)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4400.57(1) | | | | 0.59(0) | |
| 4401.10(1) | 0.86(0) | 0.71(0) | 0.73(1) | 0.85(2n) | Nd II .83(100) |
| 4401.61(4) | 1.71(1) | 1.51(1n) | 1.43(3) | 1.45(5) | Ni I .55(1000) (Fe I .30(60)) (Tb II .54(10)) |
| 4402.26(0) | 2.05(0) | 2.38(0) | 2.35(0) | 2.07(0) | (Eu II .26(2)) |
| | 2.54(0) | | | 2.48(1) | |
| 4402.78(3) | 2.88(3) | 2.88(3) | 2.86(3) | 3.05(3) | Fe II .88(2) |
| 4403.39(2) | 3.51(1) | | 3.50(2) | 3.46(0) | Sm II .36(100) (Zr II .35(6)) (Pr II .28(10)) |
| | | 3.70(1) | 3.66(0) | 3.74(0) | Pr II .60(25) |
| 4403.98(0) | | 3.90(0) | 4.22(0) | 4.16(0) | (Ti I .28(50)) |
| 4404.67(9) | 4.75(7) | 4.64(3) | 4.63(5) | 4.61(4n) | Fe I .75(1000) |
| 4405.13(1) | 5.25(1) | | | 5.12(1n) | Eu II .27(20) |
| 4405.58(0) | | 5.56(2) | 5.58(2n) | 5.43(1) | Pr II .85(80) (Tb II .41(8)) |
| 4405.78(1) | 5.74(1n) | | | | Pr II .85(80) |
| 4406.25(1) | 6.38(1) | 6.40(1n) | 6.33(1n) | | |
| 4406.68(2) | 6.67(1n) | | 6.74(3n) | 6.60(1n) | Gd II .67(400) |
| | | 6.90(1) | 6.94(1) | 6.92(1) | (Eu II .07(15)) |
| 4407.14(1) | 7.27(1) | | | 7.40(1) | Ce II .28(40?) Eu II .07(15) (Nd II .07(10)) |
| 4407.65(5) | 7.82(2) | 7.75(1) | 7.74(2) | | Ti II .68(10) Fe I .72(100) |
| 4407.89(0) | | | | 7.91(1) | (Dy II .05(2)) |
| 4408.26(4) | 8.35(2) | 8.56(1) | 8.42(0) | 8.31(1) | Gd II .25(400) Fe I .42(125) |
| 4408.74(2) | 8.84(2) | 8.68(1) | 8.78(2) | 8.86(1) | Pr II .84(200) |
| 4409.10(0) | 9.03(0) | | 9.22(0) | 9.29(1) | Ti II .22(8) (Ne II .30(150)) |
| 4409.43(4) | 9.49(2) | 9.54(2) | 9.69(3n) | 9.78(4) | Dy II .38(200) Ti II .52(10) (Tb II .51(20)) |
| 4409.96(5) | 0.05(1) | 0.10(0) | | | |
| | 0.26(0) | 0.34(1) | 0.28(1) | 0.36(0) | Nd II .25(2) |
| 4410.60(1) | | | 0.64(0) | | Ce II .64(30) |
| | 0.82(1) | | | 0.81(2) | |
| 4411.01(2) | 1.15(1n) | 0.88(1) | 1.00(1) | 1.17(1) | Ti II .08(100) Nd II .05(150) La II .21(25) (Gd (II?) .16(?)) |
| 4411.47(0) | 1.53(0) | 1.66(0) | 1.78(1) | 1.60(0) | |
| 4411.92(1) | 1.99(1) | 2.00(1) | 1.89(0) | 1.93(0) | Ti II .94(12) (Mn I .88(100)) |
| 4412.23(0) | 2.19(0) | | | 2.11(0) | (Nd II .26(20)) (Pr II .16(20)) (Eu II .38(4)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4412.84(0n) | 2.91(0) | | 2.85(0) | 2.85(0) | (Eu II .98(2)?) |
| | | | 3.11(0) | 3.28(0) | (Nd II .33(10)) (Ne II .20(50)) |
| 4413.52(3n) | 3.60(3) | 3.57(3n) | 3.66(2) | 3.74(1) | Fe II .60(0) Pr II .76(50) (Nd II .78(5?)) |
| 4413.95(1) | 4.04(0) | 4.12(0) | | | |
| 4414.56(3n) | 4.55(1) | 4.41(0) | 4.36(2) | 4.40(3) | Eu II .64(6) Pr II .40(10) (Nd II .43(8)) (Zr II .54(5)) |
| | | 4.95(1) | | 4.91(0) | (O II .89(300)) |
| 4415.08(2) | 5.20(1) | 5.10(2) | 5.14(1) | 5.20(1) | Fe I .12(600) |
| 4415.53(0) | 5.63(0) | 5.70(1) | 5.79(1) | 5.58(1) | Sc II .56(25) |
| 4415.93(1) | | | | 6.10(1n) | |
| 4416.27(1n) | 6.12(0) | 6.17(1) | 6.19(0n) | 6.14(1) | Tb II .28(20) |
| 4416.73(4) | 6.78(6) | 6.77(8) | 6.83(4) | 6.90(4) | Fe II .82(7) (Nd II .88(15)) |
| 4417.67(4) | 7.73(3n) | 7.72(2) | 7.62(2) | 7.64(3n) | Ti II .72(80) Sm II .58(80) |
| 4418.25(2) | 8.36(2) | 8.26(1) | 8.24(1) | 8.32(1n) | Ti II .34(20) (Nd II .05(1)) |
| 4418.85(2n) | 8.94(2) | 8.84(2n) | 8.90(3) | 8.91(4) | Ce II .78(200) Gd II .03(800) (Pr II .06(25)) (La II .16(30)) |
| 4419.65(3n) | 9.61(2n) | 9.59(2) | 9.61(3) | 9.59(2) | Pr II .67(30) Eu II .66(8) (Er (II?) .61(54)) (Fe III .60(10)) |
| 4420.23(0) | 0.31(0) | | | 0.10(0) | |
| | | 0.43(0) | 0.48(1n) | 0.48(0n) | Sm II .53(200) (Ho II .54(2)) |
| 4420.76(1) | 0.79(1) | 0.84(1) | 0.95(1) | | A II .90(40) |
| 4421.32(1) | 1.42(0) | 1.04(0) | | 1.09(1n) | Gd II .24(200) Sm II .14(200) Pr II .23(40) |
| 4421.85(2) | 1.94(1) | 1.70(1) | 1.90(0) | 1.85(0) | Ti II .96(35) (Ti I .76(60)) (Dy II .69(1)) |
| | 2.12(1) | 2.32(0) | 2.21(0) | 2.34(3n) | |
| 4422.56(3n) | 2.56(1) | 2.46(0n) | 2.60(0) | 2.54(0) | Fe I .57(300) Gd II .55(20) |
| 4422.83(0) | 2.89(1) | 2.83(0) | | 2.80(0) | Ti I .83(80) |
| 4423.29(0) | 3.29(1) | 3.23(0) | 3.22(1) | | (Ti II .27(pr)) |
| 4423.79(0n) | | 3.66(0) | | 3.64(1) | Ce II .68(25?) |
| 4423.89(1) | 3.86(0) | 3.98(0) | | 3.88(1) | |
| 4424.45(2) | 4.43(1) | 4.36(0) | 4.15(2n) | 4.24(3) | Sm II .34(600) Gd II .10(40) (Pr II .60(25)) |
| 4424.95(0) | 4.99(1) | 4.85(1) | | 4.74(0) | |
| | | | 5.21(1) | 5.26(1n) | |
| 4425.53(2) | 5.57(1) | 5.78(0) | 5.62(0) | 5.78(0) | |
| 4426.03(0) | | | 6.03(0) | 6.23(0) | Gd II .15(80) A II .01(300) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4426.64(0) | 6.45(0) | 6.39(0) | | | Eu II .42(5) (Nd II .82(4)) |
| 4427.06(1) | 7.08(1) | 6.96(0) | 6.97(0) | 7.09(1) | Gd II .03(20) Ti I .10(125) (Nd II .82(4)) |
| 4427.36(0) | 7.36(1) | 7.32(1) | 7.40(0) | | Fe I .31(500) |
| | | 7.78(1) | | 7.64(0) | Gd II .61(60) La II .52(100) |
| 4427.88(2n) | 7.94(1) | 8.03(1) | 7.85(1) | 8.07(1) | Mg II .00(7) (Ce II .92(6?)) (Ti II .92(pr)) |
| 4428.38(0) | 8.56(0) | | 8.45(0) | 8.61(1) | (Ne II .54(100)) |
| 4429.30(2n) | 9.24(0) | 9.10(1) | 9.18(3) | 9.27(2) | Pr II .24(100) Ce II .27(100) (Zr II .34(2)) |
| 4429.90(1) | 0.07(1) | 9.92(0) | 9.83(0) | | La II .90(400) Eu II .76(15) (A II .18(100)) (Tb II .13(2)) |
| 4430.43(3) | 0.49(2) | 0.40(0) | 0.29(1n) | 0.32(2n) | Fe I .62(200) (Ne II .90(50)) (Gd II .34(5)) |
| 4431.00(1) | 1.06(1) | 1.05(1) | 0.97(2) | 0.98(2) | Dy II .00(3) |
| 4431.62(2) | 1.69(1) | 1.54(2) | 1.67(2) | 1.65(2n) | Fe II .63(1n) |
| 4432.28(0) | 2.10(0) | 2.23(0) | 2.44(0) | 2.34(1) | Pr II .34(25) (Nd II .29(4)) (S II .41(50)) |
| 4432.82(1) | 2.72(0) | 2.85(0) | 2.91(0) | 3.01(0) | (La II .95(20)) |
| 4433.28(0n) | | | | 3.10(0) | Fe I .22(150) Eu II .28(8) |
| | 3.49(0) | 3.52(0) | 3.53(1) | | Gd II .64(60) |
| 4433.83(1) | 4.04(1) | | | 3.76(1) | Sm II .88(300) Mg II .99(8) Cr II .84(1) (Ti I .00(100)) |
| 4434.35(4n) | 4.40(1) | 4.12(2) | 4.14(5) | 4.17(6) | Sm II .32(400) (Tb II .48(10)) |
| 4434.80(0) | 4.94(1) | | 4.74(0) | 4.85(1) | Eu II .81(20) |
| 4435.20(1) | 5.29(2) | 5.29(1n) | | | |
| 4435.65(4) | 5.71(2) | | 5.42(4n) | 5.44(10) | Eu II .56(3000) (Dy II .78(1)) |
| 4436.27(0) | 6.28(1) | 6.06(1) | 6.12(1) | 6.12(2) | Gd II .22(200) |
| 4436.37(1) | | | 6.56(1) | 6.61(1) | Mg II .48(5) (Eu II .59(1)) (Zr II .36(2)) (Dy II .65(1)) |
| 4436.79(1) | 6.91(1) | 6.74(1) | 6.82(1) | 6.89(1) | |
| | | 7.40(0) | 7.50(0) | 7.39(0) | Gd II .45(8) |
| 4437.66(0n) | 7.70(0) | 7.62(0) | 7.66(1) | 7.76(1) | Ce II .61(4?) |
| | | 7.91(1) | 8.04(1n) | 8.14(1) | Eu II .96(4) |
| 4438.32(2n) | 8.36(1) | | | 8.36(0) | Gd II .26(150) Pr II .18(20) Gd II .13(30) |
| 4438.87(1n) | | 8.99(1) | 9.06(1) | 8.97(1) | Nd II .00(10) (Tb II .98(10)) |
| 4439.20(1) | 9.27(0) | | | | (Ne II .30(30)) (Fe II .13(pr)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4439.87(0) | 0.12(0) | | 9.89(0) | 9.82(0) | |
| 4440.53(1n) | 0.60(1) | 0.63(1n) | | 0.56(1) | Zr II .45(10) |
| 4440.76(0) | | | 0.78(0n) | | Ce II .88(20?) |
| 4441.64(1) | 1.49(0) | | 1.56(1) | 1.48(0) | Eu II .47(15) |
| | 1.76(1) | 1.71(1) | | 1.74(1n) | (Ti II .72(pr)) |
| 4442.20(1) | 2.27(0) | 2.24(1) | 2.36(0) | | Fe I .34(400) |
| 4442.46(0) | 2.57(1) | | 2.45(0) | 2.46(1) | Eu II .42(3) |
| 4443.08(1) | 3.09(1) | 3.05(1n) | 3.09(2n) | 3.13(3n) | Fe I .20(200) Zr II .99(25) Ce II .72(50) |
| 4443.41(2) | 3.49(1) | 3.57(1) | | | (Nd II .40(2)) |
| 4443.73(3) | 3.85(2) | 3.82(2) | 3.73(2) | 3.83(2n) | Ti II .80(125) Ce II .74(18?) (La II .94(20)) |
| 4444.49(4) | 4.48(2n) | 4.46(2) | 4.44(2n) | 4.43(3) | Ce II .39(60) Fe II .56(1) Sm II .26 (150) Ti II .56(12) (Nd II .28(6)) |
| 4445.15(2n) | 5.22(2) | 5.18(1) | 5.30(1) | 5.20(1) | |
| 4445.71(0) | | | 5.62(0) | | |
| | | | 5.87(1) | 5.93(1) | Pr II .87(10) |
| 4446.08(4) | 6.23(3n) | 6.22(2n) | 6.27(2n) | 6.33(1) | Fe II .25(1n) Nd II .39(200) |
| 4446.57(1) | | | | | Gd II .49(250) F II .71(150) (F II .51(40)) |
| 4447.25(0) | 7.28(0) | 7.34(1n) | 7.01(0) | 6.98(1) | Pr II .98(20) F II .18(200) (N II .04(300)) |
| 4447.64(7) | 7.63(2) | 7.60(1n) | 7.45(2) | 7.47(4) | |
| | 7.71(1) | 7.74(1) | | 7.69(0) | Fe I .72(200) Al II .8(15) |
| | | | 7.88(1) | 8.03(3) | (Nd II .99(4)) (Dy II .23(2)) |
| 4448.36(3) | 8.50(2) | 8.44(1) | 8.42(1) | 8.50(2n) | (Dy II .23(2)) |
| 4449.27(3) | | | 9.09(1) | 9.07(2) | Ce II .34(200) Ti I .15(150) (Dy II .16(2)) |
| 4449.56(1) | 9.45(2n) | | | 9.42(1) | |
| 4449.78(1) | 9.53(1) | 9.51(2n) | 9.63(2) | 9.65(2) | Fe II .66(1n) Dy II .70(300) Pr II .87(150) (Gd II .95(15)) |
| 4450.43(2) | 0.45(2n) | 0.31(2n) | 0.35(2) | 0.32(2) | Ti II .49(50) Pr II .21(40) |
| 4450.72(0) | | 0.64(0) | | | Ce II .73(75) |
| 4450.92(1) | 0.90(0) | | 0.79(1) | 0.82(2) | Ti I .90(150) Ce II .73(75) |
| 4451.42(4) | 1.55(3) | 1.47(3n) | 1.56(4n) | 1.61(3n) | Fe II .54(4) Nd II .57(400) (Mn I .59(125)) (Eu II .63(2)) |
| 4451.82(1) | | | | | (Pr II .95(20)) |
| 4452.04(1) | 2.06(1) | 2.02(1) | 2.03(0) | 2.08(1) | (Nd II .98(50)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4452.44(0) | 2.56(1) | 2.58(1) | 2.52(1) | 2.65(2) | (P II .44(150)) |
| 4452.87(2) | | | 2.71(0) | 2.70(3) | Sm II .73(250) |
| 4453.19(1) | 3.13(2n) | 3.15(1n) | 3.21(1) | 3.18(0) | Ti I .32(150) (V II .35(30)) (Eu II .08(1)) |
| 4453.88(2) | 4.00(1) | 3.67(1n) | 3.68(1) | 3.74(2) | Gd II .93(60) Ti I .71(80) |
| 4454.29(0) | | 4.44(1n) | 4.45(0n) | 4.33(0) | Fe I .38(200) (Pr II .38(30)) |
| 4454.68(1n) | | | 4.52(1n) | 4.63(1) | Sm II .63(200) |
| 4455.17(1n) | 5.18(2) | 5.20(3n) | 5.27(3n) | 5.29(2) | Fe II .26(3) Ti I .33(150) (Dy II .49(4)) |
| 4455.67(0) | 5.80(1) | 5.83(0) | 5.92(0) | 5.92(1) | Ca I .89(100) Fe II .85(pr) (La II .79(50)) |
| 4456.53(1n) | 6.62(2n) | 6.52(1) | 6.47(2n) | 6.52(1) | Ti II .65(10) Nd II .39(40) |
| 4457.01(1n) | 6.80(1) | 6.83(1) | 7.01(1n) | 6.97(1) | Cr II .84(pr) (Ne II .95(70) |
| | 7.16(0) | 7.22(1) | | 7.01(1) | Nd II .18(5?) |
| 4457.40(0) | | | | 7.34(1) | Ti I .43(150) Zr II .42(8) |
| 4458.31(1) | 8.28(0) | 7.95(1) | 8.01(0) | 8.00(1n) | Pr II .34(25) (Fe I .11(30)) |
| 4458.60(0) | 8.76(1) | 8.71(0) | | 8.60(0) | Sm II .52(400) (Cr I .54(50)) (Tb II .45(2)) |
| 4459.14(1) | 9.22(0) | | | 9.09(1) | Fe I .12(400) Ni I .04(400) |
| 4459.53(0) | 9.73(1) | 9.55(0) | 9.67(1) | 9.77(1) | |
| 4460.17(1n) | 0.34(1) | 0.02(1) | 0.16(2) | 0.27(2) | Ce II .21(400) |
| 4460.78(1) | 0.83(1) | 1.02(1) | 0.97(3n) | 1.00(3) | Ce II .14(50) (Eu II .88(2)) |
| 4461.29(3) | 1.31(3) | | | 1.30(0) | Zr II .22(10) |
| 4461.64(2) | 1.68(3) | 1.65(6n) | 1.68(3) | 1.85(2) | Fe I .65(300) (Eu II .55(2)) |
| 4462.16(1) | 2.18(0) | | | | Eu II .14(5) Tb II .18(10) |
| | 2.53(1) | 2.60(1) | | 2.52(0) | Nd II .41(30) (Ni I .46(150)) |
| 4462.93(0) | | | 2.91(0) | 2.79(1n) | Nd II .98(250) (P II .94(70)) |
| 4463.29(1n) | 3.15(1n) | 3.23(1) | | 3.16(1) | Gd II .25(80) |
| | 3.49(1) | | 3.42(0) | 3.52(0) | Ce II .41(60) Gd II .25(80)(SII.58(200) |
| | 3.88(0) | 3.67(0) | 3.80(0n) | | (Eu II .83(3)) |
| 4464.38(2) | 4.48(2n) | 4.53(2n) | 4.37(2) | 4.39(3) | Ti II .46(40) (S II .42(100)) |
| 4465.05(1) | 5.12(1) | 5.19(0) | 5.07(1) | 5.13(1) | Eu II .97(200) Cr II .00(1) (Nd II .08(10)) |
| 4465.62(1n) | 5.73(2) | 5.78(1) | 5.85(1) | 5.71(1) | Cr II .78(4) (Ti I .81(100)) (Nd II .60(10)) |
| | 6.13(1) | | | 5.95(0) | Pr II .98(25) (P II .10(30)) (Eu II .01(3)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4466.50(3) | 6.53(2) | 6.47(1) | 6.52(0n) | 6.44(2n) | Fe I .55(500) Gd II .55(500) |
| 4467.40(2n) | 7.22(1) | 7.29(1) | 7.24(1) | 7.28(2n) | Gd II .23(80) Sm II .34(500) |
| 4467.69(1) | 7.58(1) | | | 7.62(1) | Ce II .54(5?) |
| 4467.82(1) | 7.89(1) | 7.80(0) | 7.95(1) | 8.00(1) | Dy II .16(60) Dy II .89(20) (P II .97(50)) (Nd II .85(3)) |
| 4468.43(4) | 8.56(3) | 8.44(2n) | 8.51(2) | 8.51(3n) | Ti II .50(150) (Pr II .71(150)) |
| 4469.09(1) | | | 9.08(0) | 9.10(1) | Ti II .16(1) |
| 4469.32(0) | 9.26(1) | 9.34(1n) | | 9.23(1) | Fe I .38(200) (Nd II .26(8)) (Ce I .37(12)) |
| | 9.66(0) | | 9.62(1) | 9.74(1) | Eu II .64(6) Tb II .68(8) |
| 4470.01(1) | 0.15(1) | | | | Ce II .85(4?) (Mn I .14(80)) |
| | | | | 0.39(0) | |
| 4470.73(2) | 0.99(1n) | 0.62(1) | 0.68(1) | 0.90(1) | Ti II .86(25) (Nd II .96(6)) |
| 4471.18(2) | 1.30(2) | 1.12(2n) | 1.20(2n) | 1.28(1) | Gd II .29(200) Ce II .24(200) (Ti I .24(100)) |
| | 1.78(1) | 1.47(1) | 1.63(1n) | 1.70(2) | Eu II .64(4) Nd II .41(10) (Tb II .72(5)) (He I .48(100)) |
| 4471.97(1n) | | 1.93(0) | | | |
| | 2.18(1) | 2.26(0) | 2.24(1) | 2.36(1) | Eu II .34(6) |
| | | | | 2.78(1) | (Mn I .79(100)) (Eu II .87(1)) |
| 4472.78(3) | 2.87(3n) | 2.86(3n) | 2.93(3n) | 3.05(2) | Fe II .92(2) Sm II .02(150) (Tb II .84(3)) |
| 4473.26(1) | 3.39(1) | | 3.34(1) | 3.38(2) | |
| 4473.66(0) | 3.88(1) | 3.67(0) | | | |
| 4474.11(1) | 4.23(1) | 4.10(1) | 4.30(1n) | 4.26(1n) | Fe II .19(0) (Gd II .14(150)) (La II .03(10)) |
| 4474.82(1) | 4.80(1) | | 4.98(1n) | 4.85(0) | Ti I .85(80) |
| 4475.18(0) | 5.10(1) | 5.22(1) | 5.12(0) | 5.21(0) | P II .26(150) (Cl II .28(12)) |
| 4475.48(1) | 5.57(0) | | | 5.53(0) | |
| 4475.90(1) | 6.06(1) | 5.89(1) | 6.03(1n) | 6.02(1) | Fe I .02(500) |
| 4476.57(0) | 6.58(0) | | | 6.50(1) | |
| | | 6.92(1n) | 6.94(1) | 6.95(1) | (Eu II .89(1)) |
| 4477.18(1) | 7.16(5) | | 7.40(1) | 7.41(1) | Pr II .26(40) Nd II .45(6) |
| 4477.74(0) | 7.83(0) | | 7.79(0) | | |
| 4478.08(0) | | | 8.13(0) | 8.04(0) | |
| 4478.66(1n) | 8.66(1) | 8.66(1) | 8.56(2) | 8.63(2n) | Gd II .80(250) Mn II .74(1) Sm II .66(125) (Gd II .48(6)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4479.22(0) | 9.35(0) | | 9.38(1n) | 9.33(1n) | Ce II .36(50) Ce II .43(30) |
| 4479.71(0) | 9.87(1) | | | 9.77(1) | Ti I .70(70) (Tb II .04(2)) |
| 4480.57(1) | 0.70(0) | 0.55(0) | | 0.50(1) | Fe II .69(1) |
| 4481.19(x) | 1.22(x) | 1.20(x) | 1.23(x) | 1.18(9) | Mg II .33(100) (Cr II .49(1)) (Pr II .41(10)) (Gd II .06(300)) (Tm II .27(200)) |
| | 1.92(1) | 1.92(1) | | 1.89(1) | (Cl II .02(10)) (A II .85(80)) (Zr II .04(3)) |
| 4482.08(2) | 2.23(1n) | | 2.04(1) | 2.13(2n) | Fe I .17(150) Fe I .26(15) |
| 4482.68(1) | | 2.57(0) | 2.60(0) | 2.77(1) | (Ti I .69(40)) |
| 4482.99(0) | 2.92(0) | | | 2.83(0) | |
| 4483.46(3) | 3.50(2n) | 3.23(1) | 3.25(4) | 3.30(6) | Gd II .33(300) (S II .42(100)) |
| 4483.88(1) | 3.90(1) | 3.86(0) | 3.76(1) | 3.92(1) | Ce II .90(100) |
| 4484.17(0) | | | 4.34(0) | | Fe I .22(125) (Eu II .07(2)) |
| | 4.46(0) | | 4.42(0) | 4.48(0) | Gd II .47(20) |
| 4485.19(0) | 5.25(0) | | | 5.04(0) | Eu II .15(100) |
| 4485.63(1) | 5.71(0) | | 5.58(0) | 5.64(0) | Fe I .68(50) (Eu II .52(4)) (Zr II .44(2)) |
| 4486.14(1) | | 6.04(0) | 5.90(0n) | 6.07(0) | (Nd II .95(3)) |
| 4486.41(0) | 6.48(0) | 6.22(0) | 6.30(0) | | Gd II .35(100) |
| 4486.81(1) | 7.00(0) | 6.72(1) | 6.77(1) | 6.96(1) | Ce II .91(150) |
| 4487.41(2) | 7.57(1) | 7.45(1) | 7.56(2) | 7.60(1) | (Nd II .62(2)) (Eu II .79(1)) |
| 4487.88(0) | 7.99(0) | 8.10(1) | | | Pr II .82(20) Pr II .17(20) |
| 4488.29(2) | 8.42(2) | 8.34(1) | 8.30(2) | 8.33(5) | Ti II .32(125) Eu II .28(15) |
| 4488.52(1) | | | | | Gd II .40(80) |
| 4489.08(4) | 9.13(6) | 9.11(7n) | 9.16(5) | 9.22(7) | Fe II .18(4) (Ti I .09(100)) |
| 4489.35(1) | | | | | (Eu II .26(2)) (O II .47(10)) |
| 4489.89(1) | 9.97(1) | 9.79(1) | 9.78(0) | 9.86(2) | Fe I .74(100) Ce II .00(50) (Mn I .08(100)) (Tb II .76(3)) |
| 4490.52(1) | 0.53(0) | 0.58(0n) | | 0.54(0) | (Fe I .76(40)) (Tb II .63(8)) (Eu II .59(2)) (Nd II .77(2)) |
| 4490.91(0) | | | 0.98(1n) | 1.14(1) | Ce II .10(50?) |
| 4491.30(4) | 1.36(4) | 1.36(5) | 1.41(3n) | 1.46(3) | Fe II .41(5) (Nd II .64(3)) |
| 4492.11(1n) | 2.03(0) | 1.95(1) | 2.16(0) | 1.96(1) | |
| | 2.68(0) | 2.52(0n) | 2.58(1) | 2.54(0) | Pr II .43(15) Nd II .47(3) |
| 4492.89(0) | 3.11(0) | | | 2.76(0) | |
| 4493.44(2) | 3.55(2) | 3.44(3) | 3.45(4) | 3.49(4) | Fe II .58(1n) (Ti II .53(8)) (Nd II .42(8)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4494.26(0) | 4.16(0) | 4.30(0) | 4.29(2) | 4.34(4) | (Pr II .19(20)) (Zr II .41(8)) |
| 4494.60(3) | 4.59(1) | | | | Fe I .57(400) |
| 4495.18(1) | 5.12(0) | 5.17(0) | 4.86(0) | 4.97(1) | Gd II .85(25) Eu II .05(15) (Tb II .03(2)) |
| 4495.48(1) | 5.50(1) | | 5.44(1n) | 5.37(0) | (Ti II .43(pr)) (Ce II .39(4)) (Zr II .44(3)) |
| | 5.68(0) | | | 5.74(0) | (Fe II .52(pr)) |
| 4495.90(0) | | | 5.77(0) | 6.00(0) | (Eu II .98(2)) |
| 4496.38(0) | 6.19(0) | 6.25(0) | | 6.41(0) | Pr II .43(250) (Ti I .15(60)) |
| 4496.95(1) | 7.06(0) | | 7.02(1) | 6.99(0) | Zr II .96(15) Mn II .99(2) Cr I .86(200) |
| | | | 7.54(0) | 7.40(0) | (Eu II .45(4)) (Nd II .92(8)) |
| 4497.68(1) | 7.94(0) | 7.71(0) | | 7.81(0) | Ce II .85(25) (Nd II .92(8)) |
| | | | 8.21(1) | 8.36(2) | Gd II .28(300) |
| 4498.50(1n) | 8.55(0) | | | | |
| 4498.89(0) | 8.68(1) | | | 8.80(0) | La II .76(10) (Ne II .00(20)) (Tb II .96(1)) |
| 4499.18(0) | 9.29(0) | | 9.19(1) | 9.27(2) | |
| 4499.60(2) | 9.70(1) | 9.67(1) | 9.70(2) | 9.78(3) | Fe II .71(0) (Sm II .48(125)) |
| 4500.27(1) | 0.02(0) | 0.26(0n) | | | Eu II .27(30) |
| 4500.55(0) | 0.53(1) | 0.41(1) | 0.38(3) | 0.48(4) | (Gd II .64(20)) |
| 4501.19(6) | 1.35(4) | 1.12(3) | 1.17(4) | 1.19(6) | Ti II .27(100) |
| 4501.86(0) | 1.96(1) | 1.92(1) | 1.85(1n) | 1.77(1) | Nd II .81(50) |
| 4502.35(1) | 2.31(1) | | 2.31(0) | 2.23(1n) | Mn I .22(125) (La II .16(10)) (Eu II .10(2)) |
| 4502.99(3) | 3.07(2n) | 2.83(1) | 2.80(2) | 2.83(3) | (Dy II .25(25)) |
| 4503.76(0) | | 3.57(0) | 3.52(1) | 3.57(1) | (Tb II .58(2)) (Mn I .87(60)) |
| | | | 4.09(0) | 4.05(0) | |
| 4504.34(0) | 4.24(0n) | | 4.40(0) | 4.52(0) | Eu II .52(4) (?Cr II .52(pr)) |
| 4504.80(0) | 4.92(0) | 4.94(1n) | 4.91(1n) | 4.99(0) | Eu II .98(3) |
| 4505.63(0) | | 5.97(1n) | 5.99(1) | 5.79(0) | (Nd II .75(8?)) (Cu II .00(50)) (Eu II .73(2)) |
| | 6.28(0) | | 6.50(0) | 6.31(0) | Gd II .33(200) |
| 4507.02(3) | 7.13(2) | 7.03(2n) | 7.08(2n) | 6.83(1) | Gd II .93(60) Fe II .20(0) |
| | | | | 7.26(1) | Fe II .20(0) (Cr II .19(pr)) |
| 4507.52(1) | 7.61(0) | | 7.42(0) | | |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4508.20(7) | 8.26(7) | 8.24(8) | 8.26(6) | 8.31(5n) | Fe II .28(8) |
| 4509.16(1n) | 9.24(1) | 9.00(1n) | 9.12(1n) | 9.05(1) | Gd II .08(50) (Tb II .03(15)) |
| | 9.41(1n) | | | 9.27(1) | |
| 4510.05(3) | 0.17(1) | 9.92(1n) | 0.00(3n) | 9.99(3n) | Pr II .16(100) Mn II .21(3) |
| | | | | 0.26(1) | Mn II .21(3) |
| 4510.75(0) | | 0.70(0) | 0.76(1) | 0.87(0) | A I .73(1000) |
| 4511.62(2) | 1.70(1) | | | 1.61(0) | (Eu II .53(3)) |
| 4511.92(1) | 1.96(1) | 1.86(2n) | 1.95(2n) | 1.85(0) | Sm II .83(200) (Cr II .82(pr)) |
| 4512.18(1) | | 2.24(0) | | 2.17(1) | |
| 4512.51(0) | | | 2.59(0n) | 2.71(0) | Ti I .74(100) (Eu II .62(2)) |
| 4512.87(0) | | 3.03(0n) | 3.05(1) | 3.01(0) | Tb II .97(8) |
| 4513.34(1) | 3.28(1) | | | 3.43(1) | Nd II .33(20) |
| 4514.14(9) | 4.25(3) | 4.01(3) | 4.06(8) | 4.09(7) | (Tb II .31(8)) |
| 4514.62(1) | 4.66(1) | 4.47(3) | 4.55(1) | 4.56(1) | Gd II .50(200) (Gd II .67(5)) |
| 4515.24(7) | 5.38(7) | 5.35(7n) | 5.35(7n) | 5.41(6) | Fe II .34(7) |
| 4515.64(3) | 5.85(2) | 5.71(1n) | 5.80(1) | 5.92(1) | (Tb II .87(6)) |
| 4516.28(1) | 6.35(1) | 6.51(1n) | 6.48(1n) | 6.50(0) | Nd II .35(30) (Cr II .56(pr)) |
| 4516.62(1) | | | | | Nd II .64(4) (Cr II .56(pr)) |
| 4517.10(2) | 7.23(1) | 7.13(1n) | 7.06(0) | 7.26(1) | Gd II .10(30) Eu II .36(6) (Eu II .94(4)) |
| 4517.67(0) | | | | 7.61(0) | Pr II .60(40) |
| 4518.25(1) | 8.36(1) | 8.23(0n) | 8.22(1) | 8.36(2) | (Ti I .03(100)) |
| 4518.60(1) | 8.50(0) | | | 8.75(1) | Dy II .54(15) Eu II .70(8) |
| 4519.11(0) | 9.03(0) | | | 8.95(1) | |
| 4519.58(1) | | | 9.49(0n) | 9.49(1) | Sm II .63(200) (Eu II .54(4)) |
| 4520.12(5) | 0.17(5) | 0.16(7) | 0.25(5) | 0.21(3) | Fe II .24(7) (Gd II .07(150)) (Tb II .09(4)) |
| 4520.76(1) | 0.91(1) | 0.83(1) | | 0.94(1n) | Pr II .78(8) |
| 4521.40(0) | | | 1.19(0) | 1.31(1) | Gd II .30(100) |
| 4522.02(1) | 1.76(0) | 1.82(0n) | 2.06(1) | 1.95(2) | Gd II .94(150) |
| | | | | 2.46(3) | Eu II .57(2000) (La II .37(400)) |
| 4522.56(7n) | 2.64(7) | 2.61(8) | 2.66(7) | 2.65(9n) | Fe II .63(9) Eu II .57(2000) |
| | | | | 2.76(4) | Fe II .63(19) (Gd II .82(250)) (Nd II .84(4)) (Ti I .80(100)) |
| 4522.95(1) | 3.12(1) | | | 3.26(1) | Ce II .08(125) Sm II .04(150) (P II .92(50)) (Mn I .39(50)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4523.61(0) | 3.52(0) | 3.48(1) | 3.68(0) | 3.70(0) | Nd II .57(4) |
| 4524.28(0n) | 4.38(0) | 4.48(1) | | 4.43(0) | Gd II .39(15) |
| | | | 4.67(1n) | 4.66(1) | Ti II .73(10) |
| 4525.02(1n) | 5.08(1n) | | 5.27(1) | 5.21(0) | Fe I .15(100) La II .31(100) (S II .95(150)) (Tb II .99(8)) |
| 4525.78(0) | | | | 5.79(0) | Gd II .61(5) |
| | | | | 6.06(1) | La II .12(200) |
| 4526.32(2) | 6.38(2n) | 6.40(1n) | 6.34(1n) | 6.36(0) | (Cl I .21(25)) |
| | 6.55(1) | | | 6.64(1) | Fe II .58(1) (Tm II .56(80)) |
| 4526.96(0) | 7.08(0) | 7.06(1) | | | (Er (II?) .92(52)) |
| 4527.41(1) | 7.50(1) | 7.36(1) | 7.34(1) | 7.47(3) | Ce II .35(200) Ti I .31(100) (Er (II?) .24(510)) |
| 4527.85(0) | | | 7.92(0) | 7.91(0) | Dy II .78(30) |
| 4528.42(2) | 8.52(1) | 8.38(1n) | 8.45(2) | 8.35(2n) | V II .51(300) Ce II .47(150) |
| | 8.68(1) | 8.68(1n) | | 8.52(1) | Fe I .62(600) |
| 4528.93(0) | | | 9.13(0) | 9.11(0) | (Al III .18(6)) |
| 4529.40(3) | 9.59(2) | 9.53(1n) | 9.52(2) | 9.55(2n) | Ti II .46(40) (Fe II .56(pr)) (Tm II .38(80)) |
| 4529.80(1) | | | | | Pr II .93(10) |
| 4530.49(1) | 0.54(1) | 0.43(0) | 0.31(0) | 0.32(1) | Gd II .65(4) (Nd II .33(4)) (La II .54(15)) |
| 4531.00(0) | | | 0.87(1) | 0.89(1) | Cr I .74(150) (Co I .96(1000)) (P II .78(150)) |
| 4531.08(0) | | | | 1.15(1) | Fe I .15(125) (Pr II .09(20)) |
| 4531.72(1) | 1.89(1) | 1.80(1) | 1.86(1) | 1.67(1) | Tb II .83(6) |
| 4532.04(0) | 2.29(0) | | | 2.09(2) | |
| 4532.60(1) | 2.50(0) | | 2.41(0) | 2.55(1) | |
| 4533.25(3) | 3.28(1) | 3.18(1) | 3.02(2n) | 2.97(3n) | Ti I .24(150) (Eu II .08(2)) |
| | | | 3.34(0) | 3.43(1) | (Eu II .63(5)) |
| | | | 3.84(1) | 3.96(5n) | Ti II .97(150) |
| 4536.00(9) | 4.08(8) | 4.04(8) | 4.02(5) | 3.91(8n) | Fe II .17(2) Ti II .97(150) (Pr II .15 (60)) (P II .81(15)) (Mg II .26(4)) |
| | | | 4.21(3) | 4.25(3) | Fe II .17(2) |
| 4534.90(1) | 5.02(1) | 4.89(1) | 4.89(1) | 4.86(2) | |
| 4535.68(2) | 5.90(1) | 5.58(1n) | 5.70(1) | 5.75(1n) | Ti I .58(80) Cr I .72(125) (Pr II .92(60)) (Ti I .92(40)) |
| 4536.23(1) | | | 6.40(0) | 6.31(1) | (Gd II .56(5)) |

TABLE 3 -- Continued

| 0.756 | 1.482 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4536.76(1n) | 6.82(0) | 6.84(0) | | 6.77(1) | (Cl II .78(20)) (Tb II .93(8)) |
| 4537.11(1) | | | | | |
| | | | 7.50(0) | 7.49(1) | |
| 4537.91(1n) | 7.83(1) | 7.81(0) | | 7.91(1) | Sm II .95(200) |
| 4538.23(0) | | | 8.46(0) | 8.36(0) | |
| 4538.61(1) | 8.65(1) | | | | Dy II .76(20) (Eu II .55(2)) (Tb II .74(2)) |
| 4538.96(1) | | 8.82(1) | 8.96(1) | 8.93(2) | La II .87(8) |
| 4539.54(2) | 9.60(2) | | | | Cr II .62(2) |
| 4539.76(0) | *9.70(3) | 9.63(4) | 9.70(4) | 9.78(4) | Ce II .76(200) Cr II .62(2) (Eu II .69(3)) |
| 4540.20(1) | | | 9.91(1) | 0.12(1) | Gd II .02(200) (Tb II .23(4)) |
| 4540.42(0) | | | 0.58(1) | 0.60(2) | (Tb II .58(3)) |
| 4540.85(3) | | 0.81(1) | 0.67(1) | | (La II .71(10)) |
| | | | 1.11(0) | 1.21(1) | Nd II .27(50) |
| 4541.41(4) | 1.50(4) | 1.47(5) | 1.53(6) | 1.59(9) | Fe II .52(4) |
| 4541.75(1) | | | | | Dy II .70(30) |
| 4542.19(0) | | | | 2.17(1) | |
| 4542.62(0) | 2.66(0) | 2.61(0) | 2.51(0n) | 2.65(1) | Nd II .60(60) Pr II .54(15) (Cr II .77(pr)) (Tb II .4(4)) |
| 4543.02(0) | | | 3.08(0) | 3.04(0) | |
| | | | | 3.77(1) | |
| 4544.02(1n) | | | 3.90(1) | 4.20(1) | Ti II .01(20) Sm II .95(250) (Nd II .26(2)) |
| 4544.46(1) | | | 4.39(1n) | | Cr I .62(100) Ti I .69(150) (Mn .41(60)) |
| 4545.04(2) | | 4.95(1) | 5.04(1) | 5.06(2n) | Ti II .14(15) Ce II .96(5) (A II .08(200)) |
| 4545.36(0) | 5.35(1) | | | | Eu II .45(3) Nd II .33(2) (Dy II .35(1)) (Cr II .49(pr)) |
| | | | | 5.73(1) | |
| 4545.92(1) | | 5.90(0) | | | Cr I .96(200) |
| 4546.64(2) | 6.78(1) | 6.60(1) | 6.59(2) | 6.60(5) | Cr II .62(1) |
| 4547.18(0) | | 7.16(1) | | 7.04(0) | Eu II .22(3) (Ni II .15(?)) |
| | | | 7.45(0) | 7.44(1) | |
| 4547.77(1) | | 7.99(0) | | 7.99(0) | Fe I .85(200) |

* Phase 1.482 discontinued at wave length 4539.7

TABLE 3 -- Continued

| 0.756 | 1.642 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4548.49(1n) | | 8.37(1n) | 8.37(1n) | 8.57(1) | Pr II .54(15) (Mn I .58(80)) |
| 4549.06(2) | | | | | Nd II .02(3) |
| 4549.44(9) | 9.44(9) | 9.39(9) | 9.49(x) | 9.49(x) | Fe II .47(10) (Fe II .21(4)) (Eu II .52(6)) (S II .55(80)) |
| 4549.65(4) | | | | | Ti II .63(200) (Co I .66(600)) (Tb II .70(8)) |
| 4550.18(1) | | 0.07(0) | 0.08(0) | 0.16(1) | (Gd II .05(3)) |
| 4550.59(1) | | 0.73(0) | 0.67(1) | 0.76(2) | Gd II .95(150) Dy II .89(15) Pr II .77 (15) Pr II .88(15) (Gd II .41(3)) |
| 4551.05(1) | 1.14(0) | 1.22(1) | 1.28(1) | | Ce II .30(20) Gd II .95(150) |
| 4551.52(2) | | | 1.33(1n) | 1.35(4) | Gd II .46(30) Ce II .30(20) |
| 4552.02(1) | | | 1.96(1) | 1.98(1) | Eu II .14(5) |
| 4552.35(2) | | | 2.40(1n) | | S II .38(200) Eu II .28(6) (Nd II .28 (2)) (Gd II .44(2)) (Ti II .29(pr)) |
| 4552.72(1) | 2.57(1) | 2.52(2) | 2.65(0) | 2.60(1) | Sm II .66(150) (Si III .61(9)) |
| 4553.75(1) | | 3.63(1) | 3.56(1) | 3.59(1) | |
| 4553.96(1) | | | | 3.90(0) | Zr II .96(12) Ba II .04(200) |
| 4554.49(1) | | 4.41(0) | 4.41(1) | 4.30(1) | |
| 4554.86(3) | 5.02(4) | 4.98(5) | 5.05(6) | 5.12(3) | Cr II .03(20) Gd II .99(50) |
| 4555.52(0) | | | | 5.50(1) | Ti I .49(125) (Eu II .39(4)) (Eu II .59(6)) |
| 4555.81(4) | 5.93(4) | 5.82(6) | 5.92(7) | 5.95(3) | Fe II .90(8) |
| 4556.30(1) | | | | | Fe I .12(150) (Nd II .14(12)) |
| 4556.60(1) | 6.54(1) | 6.47(1) | | 6.47(2) | Dy II .46(1) |
| 4556.89(1) | | | 6.93(0) | | Nd II .74(12) (Tb II .92(8)) |
| 4557.13(0) | | 7.24(1n) | 7.36(1) | | (Tb II .29(2)) |
| 4557.56(1) | | | 7.72(1n) | 7.40(0) | |
| 4558.13(2) | | | | 8.16(1) | Gd II .08(250) (P II .03(100)) |
| 4558.57(7) | 8.71(8) | 8.67(9) | 8.70(9) | 8.76(6) | Cr II .66(100) (Cr II .83(pr)) |
| 4559.46(1n) | | 9.41(1) | 9.41(1) | 9.43(1) | La II .28(100) |
| 4560.19(1) | | 0.14(1) | 0.21(0) | 0.28(1) | Ce II .28(125) |
| 4561.08(1) | | 0.92(0) | 0.96(1) | 1.01(2) | Ce II .96(60) (Nd II .18(8)) |
| 4561.67(1) | | | 1.53(1) | 1.46(1) | (Pr II .46(6)) |
| 4562.32(2) | | 2.22(1) | 2.29(1) | 2.12(1) | Tb II .25(8) (Eu II .18(1)) |
| 4562.51(0) | | | | 2.50(1) | Ce II .36(400) (La II .5(5)) |
| 4563.11(1) | | 3.08(1) | 3.10(1) | 3.15(1) | Pr II .13(30) Nd II .22(40) (Gd II .03(4)) |

TABLE 3 -- Continued

| 0.756 | 1.642 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4563.69(2) | 3.94(1) | 3.62(1n) | 3.71(2) | 3.79(3) | Ti II .77(200) (Tb II .68(20)) |
| 4564.15(1) | | | 4.30(1) | 4.37(1) | Cr II .27(1) |
| 4564.60(0) | | 4.53(0) | 4.48(1) | 4.55(0) | V II .59(200) |
| 4565.06(0) | | 5.14(0) | 5.24(0) | 5.22(0n) | (P II .21(100)) (Eu II .93(2)) |
| 4565.63(3) | 5.75(3) | 5.70(5) | 5.82(4) | 5.91(3) | Cr II .78(10) Ce II .84(50) (Eu II .57(5) |
| 4566.56(1) | | 6.59(1) | 6.56(1) | 6.54(1) | |
| 4567.24(0) | | 7.16(0) | 7.10(0) | 7.15(0) | |
| 4567.68(1) | 7.91(1) | 7.79(0) | 7.84(1) | 7.85(0n) | Nd II .61(12) (Tb II .72(6)) (Si III .83(7)) |
| 4568.53(0) | | 8.46(0) | | 8.37(0) | Ti II .31(8) Pr II .54(30?) |
| 4568.96(1) | | 9.09(1) | | 8.73(1) | |
| 4569.32(2) | | 9.25(0n) | 9.20(1) | 9.24(1) | (Tb II .29(2)) |
| 4570.26(0) | | | | 0.20(1) | |
| 4570.58(0) | | 0.42(0) | 0.52(0) | 0.55(1n) | Pr II .56(20) |
| 4571.19(1) | | | | 1.04(1) | Gd II .98(40) Mg I .15(20) La II .97(10) (Cr II .24(pr)) |
| | | | 1.46(0) | 1.34(1) | (Tb II .42(1)) (Gd II .54(2)) |
| 4571.99(8n) | 2.13(1) | 1.86(2n) | 1.99(3n) | 1.87(5) | Ti II .98(300) |
| 4572.40(0) | | 2.12(1) | | 2.36(2) | Ce II .28(250) (Cl II .13(100)) |
| 4572.96(5) | 3.07(1) | 2.81(1) | 2.78(3) | 2.85(5) | (Cr II .83(pr)) (Tb II .18(8)) |
| 4573.61(1) | | 3.55(0) | 3.60(1) | 3.66(2n) | Eu II .66(4) (Cr II .63(pr)) |
| 4573.93(1) | | | | 3.87(2n) | Dy II .87(2) |
| 4574.29(0) | | 4.49(0) | 4.36(1) | 4.42(2) | Zr II .49(6) |
| 4574.65(2) | 4.67(1) | | | | (Fe I .72(12)) |
| 4575.03(0) | | | | 4.89(0) | La II .88(200) (Eu II .00(2)) |
| 4575.62(3n) | | 5.35(0) | 5.43(1) | 5.46(4) | (Tb II .42(2)) |
| 4576.28(3) | 6.38(3) | 6.32(6) | 6.35(4) | 6.42(4) | Fe II .33(4) Eu II .35(12) (Pr II .32(20)) |
| 4576.58(1) | | | | | Dy II .60(2) |
| 4576.98(0) | | 7.03(1) | 6.98(0) | | Eu II .93(10) |
| 4577.24(2) | | | 7.10(1) | 7.12(1) | |
| | | 7.39(1) | 7.43(1) | | |
| | | | | 7.55(1) | Sm II .69(250) |
| 4577.91(1) | 8.18(0) | 7.95(1n) | 7.98(1) | 8.08(1) | (Pr II .14(25)) |

TABLE 3 -- Continued

| 0.756 | 1.642 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4578.76(0) | | 8.96(0) | | 8.70(1) | Tb II .62(30) (Nd II .88(30)) |
| | | | | 9.26(1) | Nd II .31(30) (A II .39(80)) |
| 4579.42(3) | 9.45(1) | 9.50(2n) | 9.50(2n) | 9.66(2) | Fe II .52(1) Mn I .67(50) |
| 4579.99(3) | 0.27(0) | 0.07(1) | 0.07(2n) | 0.15(3) | Fe II .05(1) Cr I .06(300) Eu II .23(5) (La II .05(150)) |
| 4580.45(1) | | | | | Ti II .46(5) |
| 4581.18(1) | | 0.82(1n) | 0.86(0) | 0.90(1n) | Gd II .09(200) Cr I .06(300) |
| | | 1.43(1n) | 1.46(1) | 1.57(1) | Fe I .52(60) Co I .60(1000) Pr II .58(10) |
| 4581.72(1) | | | | | (Mn I .83(125)) (Eu II .62(5)) |
| 4582.48(1) | | 2.34(0) | 2.33(1) | 2.44(1n) | Gd II .53(400) Gd II .38(300) (Ce II .50(50?)) (Tb II .57(6)) |
| 4582.72(5) | 2.85(4) | 2.79(4n) | 2.73(3n) | 2.92(2n) | Fe II .84(3) |
| 4583.38(0) | | | | 3.35(0) | Ti II .44(10) Gd II .33(20) |
| 4583.78(8) | 3.90(5) | 3.81(9) | 3.86(9) | 3.94(9) | Fe II .85(11) |
| 4584.03(2) | | | | | Nd II .04(4) |
| 4584.36(1) | | | | 4.54(1) | |
| 4584.93(1) | | 4.76(0) | | 4.68(1n) | (Tb II .62(6)) |
| 4585.23(1) | | 5.04(0n) | 5.18(0) | 5.22(0) | |
| | | 5.90(0) | 5.95(0) | 6.03(1n) | Ca I .87(125) Eu II .68(8) (Al II .82(40)) |
| 4586.64(0) | | | | 6.58(0) | |
| 4587.13(2) | 7.41(1) | 7.25(1n) | 7.30(1) | 7.39(0) | |
| 4588.06(7) | 8.26(4) | 8.21(6) | 8.24(6) | 8.27(4) | Cr II .22(75) Dy II .93(40) (Al II .19(30)) (P II .90(300)) |
| 4589.24(1) | | 9.18(0) | 9.09(0) | 9.20(1) | |
| 4589.80(6) | 9.90(2) | 9.85(3) | 9.91(4) | 9.99(4) | Cr II .94(3) Ti II .95(100) (A II .93(150)) |
| | | 0.66(1) | | 0.53(1) | |
| 4590.80(2n) | 0.93(0n) | 0.86(2n) | 0.94(1n) | 0.95(2) | (O II .94(300)) |
| 4591.20(2n) | | 1.16(0) | | | Cr I .39(200) Cr II .39(tr) Eu (II?) .06(8?) |
| 4591.63(0) | | | | 1.74(1) | Sm II .82(100) (Dy II .78(1)) (Tb II .56(8)) |
| 4591.92(6) | 2.12(3) | 2.02(6) | 2.07(4) | 2.17(4) | Cr II .06(20) |
| 4592.70(1) | | 2.65(1) | 2.75(0) | 2.63(0) | Fe I .66(200) |
| 4593.13(0) | | 2.84(1n) | 3.06(0) | 3.08(1n) | (Cs I .18(1000R)) |

TABLE 3 -- Continued

| 0.756 | 1.642 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|---|
| 4593.69(2n) | 3.64(1) | 3.67(1n) | 3.80(2n) | 3.86(1n) | Ce II .93(200) Sm II .54(150) (Pr II .93(10)) |
| | | 4.43(0) | | | Nd II .45(6) |
| 4595.12(1) | | 4.91(1n) | 5.06(0) | 5.02(1n) | Sm II .29(250) (Dy II .14(1)) |
| 4595.54(1) | | | | | Fe II .68(pr) |
| 4595.93(2) | 6.06(1) | 5.91(3n) | 6.05(2) | 6.08(2) | (O II .13(150)) (A I .10(1000)) |
| 4597.00(1) | 7.12(0) | 6.80(1) | 6.84(1) | 6.98(1) | Gd II .98(400) (N II .01(20)) |
| 4597.52(0) | | 7.69(0) | 7.73(1) | | |
| 4598.10(1) | | | | 7.88(1) | Gd II .91(500) Fe I .14(50) |
| 4598.43(4n) | 8.56(1) | 8.44(2) | 8.46(1) | 8.53(2) | Fe II .53(1n) |
| 4599.30(1) | | 9.31(0) | | 9.21(0) | |
| 4599.89(1) | | | | 9.87(0) | |
| 4600.26(1) | | | | 0.39(0) | V II .19(150) (Ni I .37(200)) (Nd II .52(2)) |
| 4600.76(0) | | | 0.79(0) | 0.76(1) | Cr I .75(150) (Cl I .00(20)) |
| | | 1.15(0) | 0.95(0) | 0.91(0) | Gd II .05(500) |
| 4601.27(1) | *1.28(0) | 1.22(1) | 1.33(0) | 1.43(1) | Fe II .34(pr) (N II .49(100)) |
| 4601.80(0) | | | | 1.98(0) | P II .10(300) (Fe I .01(20)) (Zr II .97(2)) |
| | | | 2.28(0) | 2.32(1) | Nd II .24(2) |
| 4602.55(1) | | | | 2.78(0) | |
| 4602.96(1) | | 2.86(0) | 3.02(1) | 3.08(2) | Fe I .94(300) |
| 4603.88(1) | | 3.64(0) | 3.90(0) | 3.74(1) | (Tb II .08(3)) |
| 4604.37(2) | | | 4.44(0) | 4.20(1) | |
| 4605.27(1) | | 5.29(1n) | 5.37(0) | 5.44(1n) | Mn I .36(150) |
| 4606.49(1) | | 6.34(1n) | 6.39(1) | 6.45(1) | Ce II .40(50) Sm II .51(100) (Gd II .64(8)) |
| 4607.66(1) | | 7.74(0) | 7.70(1n) | 7.68(1n) | Fe I .65(50) Mn I .62(50) |
| 4608.78(1) | | | 8.83(0n) | 8.93(0) | |
| 4608.27(1) | | | | 9.39(0) | (Nd II .15(1?)) (Ti II .27(pr)) (O II .39(60)) |
| 4610.47(3) | | | 0.34(0n) | 0.25(2) | |
| | | 0.57(0) | 0.56(0) | 0.67(0) | |
| 4610.94(0) | | | 1.03(0) | 1.04(1) | (Gd II .94(1)) |
| 4611.29(2) | | | | 1.17(1) | Fe I .29(200) |

*Phase 1.642 discontinued at wave length 4601.3

TABLE 3 -- Continued

| 0.756 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|
| | | 1.49(1) | 1.52(0) | |
| 4611.87(0) | 1.84(1) | | | |
| | 1.96(0) | 1.97(1) | 2.12(2) | (Pr II .07(20)) |
| 4612.51(1) | 2.31(0) | | | (Eu II .43(2)) (Nd II .47(4)) |
| 4613.06(1) | 3.11(0) | 3.24(0) | | (Fe I .22(30)) (Cr I .37(150)) (La II .38(200)) |
| 4613.65(1) | 3.55(0) | | 3.62(0) | |
| 4614.45(1) | 4.53(1) | 4.56(1) | 4.65(1n) | Eu II .63(6) |
| 4615.28(2) | 5.33(0) | 5.29(1) | 5.34(2) | Sm II .44(150) (Gd II .44(3)) |
| 4615.68(0) | | 5.73(0) | 5.83(0) | Sm II .69(300) |
| 4616.07(1) | | 6.30(1) | 6.33(1) | (Cr I .14(300)) |
| 4616.51(5) | 6.62(9) | 6.65(4) | 6.74(3) | Cr II .66(18) |
| 4617.42(1) | 7.19(1) | 7.19(0) | | Dy II .27(30) Ti I .27(200) |
| 4618.17(1) | 7.88(1n) | 7.95(0n) | 8.04(2n) | |
| 4618.66(5) | 8.63(1) | | 8.59(0) | |
| 4619.05(2) | 8.82(4) | 8.84(4) | 8.88(6) | Cr II .83(35) |
| | 9.35(0) | 9.22(0) | 9.30(1) | Fe I .30(100) |
| 4619.54(1) | 9.67(1n) | 9.67(0) | 9.74(1) | Gd II .63(8) La II .87(300) |
| 4620.08(0) | | | 0.13(0) | Dy II .04(60) |
| 4620.44(4) | 0.44(5) | 0.52(4) | 0.57(4) | Fe II .51(3) (Gd II .45(15)) |
| 4621.29(6) | | 1.04(0) | 1.07(2) | (Cr II .41(pr)) |
| 4621.69(3) | 1.56(5n) | 1.62(5n) | 1.73(2n) | |
| 4622.02(0) | | 2.21(1) | 2.35(0) | (Dy II .38(1)) |
| 4622.65(0) | | | | Gd II .63(8) (P II .70(50)) |
| 4623.32(0) | | 3.50(0) | 3.53(0) | |
| 4624.38(0) | | | | (Cr II .58(2)) |
| 4625.08(2n) | 4.91(0n) | 4.99(2n) | 5.00(1n) | Fe I .06(100) Ce II .90(60) |
| 4625.37(0) | | | 5.27(0) | |
| 4625.81(2) | 5.88(1) | 5.92(2) | 6.02(2) | Fe II .91(1) |
| 4626.73(0) | 6.72(0n) | 6.86(1) | 6.78(1) | Fe II .78(pr) Tb II .91(15) |
| 4627.35(0) | 7.41(0) | | 7.24(0) | (Eu I .22(8000)) |
| 4628.19(3) | 7.97(1) | 8.07(2) | 8.11(2n) | Ce II .16(500) (Dy II .08(1)) |
| 4628.76(1) | 8.70(1) | 8.84(2) | 8.88(2) | Pr II .75(100) Fe II .82(0n) (P II .70(50)) |
| 4629.27(7) | 9.31(5) | 9.35(4) | 9.42(3) | Fe II .33(7) (Ti (II?) .34(15)) |

TABLE 3 --Continued

| 0.756 | 3.042 | 4.490 | 5.003 | Identification |
|---|---|---|---|---|
| 4629.82(0) | | 9.82(0) | 9.90(0) | Nd II .90(40) |
| 4630.12(0) | 0.24(1n) | 0.32(1) | 0.32(2) | (Fe I .13(10)) |
| 4630.50(2n) | | | 0.68(1) | (N II .55(300)) |
| 4631.07(2) | | 1.23(0) | 1.25(0) | |
| 4631.75(2) | 1.82(1n) | 1.86(2n) | 1.97(1n) | Fe II .90(0n) |
| | 2.63(1) | 2.65(1) | 2.76(1) | Nd II .69(4) |
| 4633.07(1) | 3.17(0) | | 3.09(0) | Eu II .07(8) Fe I .92(70) |
| 4633.58(0) | | | 3.78(1) | |
| 4633.94(7) | 4.06(5) | 4.12(5) | 4.15(3) | Cr II .09(25) |
| 4635.25(5) | 5.28(5) | 5.27(3) | 5.39(3) | Fe II .33(5) |
| 4636.19(1) | | | 6.08(0) | |
| | 6.50(1n) | 6.46(1) | 6.47(0) | La II .42(80) (Nd II .57(2)) (Al II .38(4)) |
| 4637.14(0) | 6.94(0) | 7.28(0) | 6.93(0) | (Cr I .18(20)) (A II .25(30)) (Tb II .00(3)) |
| | | 7.48(0) | 7.44(1) | Fe I .52(100) |
| 4637.93(2n) | 7.99(3) | 8.05(2) | 8.15(2) | Fe I .02(80) (Eu II .74(2)) |
| 4638.92(1n) | 8.99(0n) | 8.82(1) | 8.79(1) | Gd II .00(200) (O II .86(70)) (Nd II .71(10)) |
| 4639.39(0) | 9.32(0) | | | Ti I .37(80) (Nd II .38(4)) |
| 4639.90(0) | 0.15(0) | 9.91(0) | 0.05(1) | Ti I .95(60) |
| 4640.27(1) | | | 0.43(0) | Al II .36(20) Al II .38(18) |
| 4640.86(2) | 0.81(2) | 0.84(3) | 0.90(5) | Fe II .84(0) (Tb II .98(15)) |
| 4641.03(2) | | | | |
| 4641.62(0) | | | 1.64(1) | |
| 4641.90(0) | 1.86(0) | | | (O II .83(150)) (Tb II .97(30)) |
| 4642.38(0) | 2.09(1) | 2.13(1n) | 2.16(0n) | Sm II .24(500) |
| 4642.86(1n) | 2.94(1) | 2.91(1) | 2.92(1n) | (Mn I .81(50)) (N II .11(100)) |
| 4644.25(0) | 4.14(1n) | 4.29(0n) | 4.33(1) | |
| 4645.14(0) | | | 5.10(0) | Ti I .19(100) Tb II .26(50) La II .28(100) |
| 4645.88(0) | 6.18(0) | 6.15(1) | 6.05(0) | Cr I .17(100) Gd II .33(40) (Nd II .77(20)) (Pr II .06(30)) |
| | | *7.34(1) | 7.33(0) | Fe I .44(125) La II .50(100) |
| | | 8.17(1) | 8.27(1) | Sm II .16(100) (Fe II .23(pr)) (S II .17(35)) |
| 4648.54(1) | 8.76(0) | | | Ni I .66(400) (Al II .62(4)) |
| 4648.88(1) | | 8.94(0) | 8.99(0) | Fe II .93(0) (Cr I .87(50)) |

*Phase 4.490 discontinued at wave length 4647.3

TABLE 3 -- Continued

| 0.756 | 3.042 | 4.520 | 5.003 | Identification |
|---|---|---|---|---|
| 4649.49(1) | | | 9.49(0) | |
| 4650.17(0) | | | 0.11(0) | Ti I .02(60) (Nd II .23(3)) (Gd II .98(6)) |
| 4650.62(0) | 0.44(0) | | 0.67(0) | Al II .54(8) Al II .65(6) |
| 4651.10(1) | | | | (Cr I .28(100)) (Eu II .13(2)) (Tb II .07(1)) |
| 4651.60(2) | | 1.63(1) | 1.61(1) | Pr II .52(75) (Dy II .54(2)) |
| 4652.07(2) | | | | Cr I .16(200) (Fe II .28(tr)) |
| | | | 2.43(1) | Eu II .44(6) (Fe II .28(tr)) |
| 4652.73(0m) | 2.86(0) | | 2.95(0) | |
| 4654.20(3) | 4.05(1n) | 4.12(1n) | 4.12(1) | Ce II .29(30) |
| | 5.06(1) | | 5.19(1) | (Gd II .99(100)) |
| 4655.44(1) | | | | (La II .50(400)) |
| | | 5.71(1) | 5.85(0) | Ti II .71(3) |
| 4656.33(1) | | | 6.20(0) | (Fe I .47(150)) |
| 4656.87(4) | 6.89(5) | 7.03(4) | 7.08(4) | Fe II .97(1) |
| 4658.12(1) | | | 8.16(1n) | P II .11(100) |
| 4658.91(1) | 8.73(0) | 8.84(1) | 8.84(1) | (Eu II .63(15)) (Gd II .97(3)) |
| 4659.69(1n) | | | 9.69(0) | |
| 4660.66(1) | 0.56(1) | 0.57(1) | 0.59(3) | |
| | 1.54(0) | | 1.60(1) | (O II .65(125)) |
| 4662.72(0) | 2.97(1) | | 2.75(1) | La II .51(200) (Ti II .76(pr)) (Nd II .97(2)) |
| 4663.07(1) | | | | Al II .05(11) |
| 4663.66(2) | 3.63(1) | 3.73(1) | 3.68(1) | Fe II .70(0) La II .76(300) |
| 4664.24(1) | | | | Fe II .23(tr) Gd II .27(30) |
| | | | 4.46(0) | Nd II .45(4) |
| 4664.73(1) | | | | Dy II .68(80) Cr I .80(70) Pr II .65(20) |
| 4665.52(2) | 5.03(0) | | 5.25(3) | |
| | | | 6.52(1) | Gd II .45(40) |
| 4666.60(4) | 6.72(4) | 6.75(3) | 6.79(3) | Fe II .75(2) (Al II .8(5)) (Gd II .45(40)) |
| 4667.36(1) | | | 7.58(1) | Fe I .46(150) (Eu II .41(3)) |
| 4667.89(2) | | | 7.62(1) | Ti I .59(150) (Ni I .77(100)) |
| | 8.16(1) | | 8.29(1) | Fe I .14(125) |
| 4668.47(2) | | | 8.34(2) | |
| 4668.89(1) | | | 8.95(1) | La II .91(250) |

TABLE 3 -- Continued

| 0.756 | 3.042 | 4.520 | 5.003 | Identification |
|---|---|---|---|---|
| | 9.19(1) | | 9.16(0) | (Fe I .18(15)) (Cr I .34(50)) (Nd II .13(3)) |
| 4669.45(1) | | | | Sm II .40(500) Ce II .50(20) |
| | | | 9.73(1) | Sm II .65(500) |
| 4670.13(4) | 0.22(2) | | | Fe II .17(0) |
| | | | 0.35(2) | Sc II .40(300) |
| 4671.32(1n) | 1.34(1) | | 1.44(1) | (Cr II .36(pr)) |
| 4672.14(0) | | | 2.23(1) | Pr II .08(40) |
| 4672.73(1) | | | | |
| | | | 3.08(1) | Fe I .17(20) |
| 4673.27(2n) | *3.27(5n) | ‡3.34(3) | 3.46(2) | |
| 4674.65(2n) | | | 4.50(2) | Sm II .60(600) Gd II .54(8) (Cu II .76(30)) |
| 4675.32(0n) | | | 5.40(1) | Gd II .27(5) |
| 4675.80(1) | 5.90(0) | | | Gd II .78(8) |
| 4676.47(2) | | | 6.34(2) | (O II .25(125)) |
| 4676.75(0) | | | | |
| †4677.15(2) | | | 7.00(1) | Sm II .91(500) Gd II .99(8) |
| 4678.01(1) | | | 8.01(0) | |
| 4678.73(0) | | | 8.91(0) | Fe I .85(150) (P II .94(100)) (Ce II .94(pr)) |
| 4679.23(1) | | | | |
| | | | 9.93(0) | (Cr II .87(pr)) |
| 4680.31(2n) | 0.54(0) | | 0.42(1) | Ce II .13(25) Ce II .46(2?) |
| 4680.74(1) | | | | Nd II .73(30) |
| | 1.63(0) | | | |
| 4681.96(1n) | | | 1.87(1) | Gd II .85(6) Ti I .92(200) (Cu II .99(50)) (La II .12(5)) |
| 4683.14(0) | | | 3.33(0) | Si II .02(2) |
| 4683.74(1) | 3.91(1) | | 4.02(1) | |
| 4684.27(1) | | | 4.37(0) | |
| 4684.80(2) | 4.69(1) | | 4.76(2) | Cr II .77(1) Ce II .61(30) (Pr II .94(20)) |
| 4685.90(2) | | | 5.74(2) | |
| 4686.42(1) | | | 6.43(0) | |

* Phase 3.042 discontinued at wave length 4673.3

‡ Phase 4.520 discontinued at wave length 4673.3

† Phase 0.756 discontinued at wave length 4677.2

TABLE 3 -- Continued

| 0.691 | 3.721 | 5.003 | Identification |
|---|---|---|---|
| 4686.89(1) | | | |
| 4687.40(1) | 7.44(1) | 7.52(0) | |
| 4688.95(1) | | 8.74(1) | La II .65(40) (Eu II .51(3)) |
| 4689.78(1) | | 9.61(1) | Dy II .77(40) |
| 4690.97(1) | | 1.19(1) | (La II .17(50)) (Gd (?) .17(S2)) |
| 4691.43(2) | | 1.26(2) | Fe I .41(80) Ti I .34(125) |
| 4692.52(0) | | 2.49(0) | La II .50(200) |
| 4693.26(2) | | 3.31(1) | (Co I .21(500)) |
| 4693.81(0) | | 3.98(1) | |
| 4694.44(0n) | | 4.32(1) | |
| 4695.36(1) | | 5.44(1) | (Eu II .35(4)) |
| 4696.31(1n) | | 6.26(1) | (O II .32(30)) |
| | | 6.97(2) | (Cr I .06(50)) |
| 4697.28(3) | | | Fe II .32(tr) |
| 4697.97(0) | | 7.72(1) | Cr II .62(2) |
| 4698.77(1) | | 8.66(2) | Dy II .69(60) (Ti I .76(100)) (Cr II .64(pr)) |
| 4699.53(2) | | 9.47(3) | La II .63(200) (Cr .59(30)) |
| 4701.37(1) | | | (Ni I .54(150)) |
| | | 2.71(0) | |
| 4703.21(1) | | | La II .27(150) (Mg I .02(8)) (O II .14(30)) (Zr II .03(5)) |
| 4703.94(3) | | 3.77(1) | Ni I .81(200) |
| 4704.50(1) | | 4.37(0) | Sm II .40(500) (Ne I .40(1500)) |
| 4705.20(1) | | 5.20(1) | (O II .32(300)) |
| | | 6.42(0) | Nd II .54(100) |
| | | 7.51(0n) | Pr II .54(20) (Gd II .33(3)) |
| 4707.97(1) | | | Cr I .04(200) Pr II .94(60) Pr II .16(60) |
| 4708.58(2) | | 8.77(1) | Ti II .66(20) (Ne I .85(1200)) |
| 4709.07(2) | | | Fe I .96(50) (Fe I .10(20)) |
| 4709.93(1) | | 9.70(1) | Nd II .71(20) Mn .72(150) |
| 4710.61(1) | | 0.47(1) | |
| 4711.28(3) | | 1.26(1) | |
| 4711.82(0) | | 2.09(1) | Gd II .98(80) (Eu II .12(3)) (Ne I .06(1000)) (Gd II .68(6)) |

TABLE 3 -- Continued

| 0.691 | 5.003 | Identification |
|---|---|---|
| 4712.32(0) | 2.47(0) | |
| 4712.98(1) | 2.84(1) | Gd II .80(50) Sm II .06(150) La II .92(40) |
| 4713.68(2n) | 3.64(3n) | (Eu .61(400)) |
| 4715.04(3) | 4.99(3n) | Cr II .12(1) (Ce II .83(?)) |
| | 5.87(0) | Ni I .78(200) (Gd II .97(4)) |
| 4716.18(1) | | (S II .23(600)) (Eu II .29(2)) |
| 4717.15(0) | 7.20(1n) | (P II .00(15)) (Nd II .08(10)) (La II .58(50)) |
| 4717.87(1) | 8.07(0) | |
| 4718.30(0) | 8.59(1n) | Cr I .43(200) Sm II .33(150) |
| 4718.81(2) | 8.79(1) | Gd II .04(60) |
| 4719.59(1) | 9.51(2) | Ti II .52(2) |
| | 0.26(1) | ? La II .95(300) (P II .26(30)) |
| 4720.68(1) | | |
| | 0.94(1) | |
| 4721.56(0n) | | (Cl II .43(25)) (Gd II .27(50)) |
| 4723.03(3) | 2.85(3) | |
| 4723.88(0) | 3.57(1) | Gd II .73(40) |
| | *4.33(0) | Cr I .42(125) Nd II .36(20) La II .42(40) |
| 4724.65(1) | | |
| 4725.01(0) | | |
| 4725.44(1) | 5.64(2) | Gd II .78(20) Eu II .69(6) |
| 4726.17(0) | | Yb II .08(60) (Er (II?) .08(S5)) |
| 4727.14(1) | 7.00(1) | Dy II .13(50) (Cr I .15(80)) (A II .91(200)) |
| | 8.24(1) | La II .42(100) |
| 4728.56(1) | | Gd II .47(300) Fe I .56(20) (Pr II .63(15)) |
| 4729.15(0) | 9.44(0) | |
| 4729.68(0) | 9.90(0) | Cr I .72(30) |
| 4730.34(1) | | Mn II .36(int?) |
| 4730.79(0) | | |
| 4731.38(3) | 1.58(4) | Fe II .49(1) |
| 4731.82(0) | | Dy II .85(150) |
| 4732.68(0) | 2.52(1) | Gd II .60(600) |
| | 3.30(0) | (Ti I .43(25)) |

* Phase 5.003 discontinued at wave length 4724.3

TABLE 3 -- Continued

| 0.691 | 5.050 | Identification |
|---|---|---|
| | 4.17(1) | Fe II .09(3?) (Sc I .09(100)) (Pr II .18(25)) |
| 4734.67(1n) | 4.86(1) | |
| 4735.71(3) | 5.46(3) | (Gd (?) .76(S150)) |
| 4736.87(1) | 6.75(0) | Fe I .78(125) |
| 4737.38(1) | 7.23(1) | Ce II .28(60) Cr I .35(200) |
| 4738.18(0) | 8.28(0) | Mn II .29(1) (Gd (?) .13(S50)) |
| 4738.97(1) | 9.02(1) | (Mn (?) .11(150)) |
| 4739.85(0) | | (La II .80(15)) |
| 4740.60(0) | 0.35(1) | La II .27(120) |

## NOTES TO TABLE 3

λ 3865.6 and λ 3865.9 form two distinct lines on MtW 1995, while MtW 2544 shows only one broadened line. The assignment of the components to *Cr* II + *Fe* I and to *Cr* II + *Nd* II is not certain.

λ3903.8 main contributor unknown. The line is of class B.

λλ 3905.7 and 3906.0 are clearly divided on MtW 1995 but are blended on MtW 2544.

λ 3919.4 is a fairly strong unidentified line of class A.

λ 3920.6 is a strong, unidentified line of class B.

λ 3930.3 of *Fe* I and λ 3930.5 of *Eu* II are clearly double on MtW 1995 but are blended on MtW 2544.

λ 4012.3 and λ 4012.4 are single on MtW 1995, but double on MtW 2544. It is difficult to disentangle the blends contributing to these lines.

λ 4034.2 is a strong line not satisfactorily identified.

λ 4050.5 is of class B and is probably not all due to *Dy* II.

Lines *Ti* II 4053.84 and *Cr* II 4054.18 are not resolved on all plates. For phase 3.042 the two entries are two separate measures of the same blended line.

λ 4060.6 is of class B and cannot be due to *Eu* II and *Nd* II alone.

λ 4161.8 is of class B and is mostly unidentified.

λλ 4177.6 and 4177.9 are not satisfactorily identified. The latter line is of class A or is completely blended with λ 4177.6 on some plates.

λλ 4200.5 and 4200.8 are not satisfactorily identified.

λ 4288.4 is not satisfactorily identified.

λ 4289.9 is one of the most remarkable lines of class A. It is probably due to *Ce* II.

λ 4356.4 is a strong unidentified line.

λ 4371.9 is a strong unidentified line.

The line *Fe* I 4383.6 is the violet component of a double line. The red component, whose shift is not the same on all plates, has not been satisfactorily identified.

λ 4384.2 is not satisfactorily identified. Class B, very strong.

λ 4393.0, strong unidentified line.

λ 4393.7, strong unidentified line.

λ 4410.0, strong unidentified line.

λ 4410.8, strong unidentified line.

λ 4419.6, not satisfactorily identified, class B.

λ 4447.5, strong unidentified line, class A.

λ 4448.4, not satisfactorily identified.

λ 4502.9, not satisfactorily identified.

λ 4511.9, not satisfactorily identified.

λ 4514.1, very strong unidentified line of class B.

λ 4515.6, strong unidentified line.

λ 4540.8, strong unidentified line.

λ 4618.6, strong unidentified line.

λ 4621.1, strong unidentified line.

λ 4621.6, strong unidentified line.

λ 4660.6, strong unidentified line.

λ 4673.3, strong unidentified line.

λ 4722.9, strong unidentified line.

TABLE 4

Departures of Individual Lines from
Mean Plate Velocities in Km/Sec

| Laboratory λ | 0.500 | 0.691 | 0.822 | 0.981 | 1.323 | 1.460 | 1.510 | 1.642 | 2.363 | 2.580 |
|---|---|---|---|---|---|---|---|---|---|---|
| 3711.97(5) | | - 2.3(2n) | | | -15.4(8n) | | | | -19.6(2n) | |
| 3721.94(6) | | -13.5(9n) | | | -18.8(9n) | | | | - 1.6(5n) | |
| 3734.37(8) | | - 2.6(xn) | | | + 7.8(xn) | | | | - 9.2(xn) | |
| 3750.15(10) | | - 6.1(xn) | | | - 1.8(xn) | | | | - 1.5(xn) | |
| 3770.63(15) | | - 8.0(x) | | | -21.8(xn) | | | | - 2.8(xn) | |
| 3797.90(20) | | - 3.2(x) | | | - 7.9(xn) | | | | + 5.8(xn) | |
| 3835.39(40) | | + 6.6(x) | | | + 1.2(xn) | | | | - 8.0(xn) | |
| 3889.05(60) | | - 4.6(x) | + 8.0(xn) | | + 0.1(xn) | | | - 1.8(xn) | - 4.4(xn) | |
| 3970.08 | - 0.2(x) | + 3.9(x) | + 5.0(xn) | | - 3.4(xn) | + 3.4(xn) | | +10.3(xn) | + 0.7(xn) | + 4.4(xn) |
| 4101.75 | + 1.8(xn) | + 2.6(x) | - 0.3(xn) | | -11.3(xn) | - 1.6(xn) | | - 6.7(xn) | - 0.6(xn) | + 3.4(xn) |
| 4340.48(200) | | - 1.7(x) | - 4.6(xn) | | - 5.2(xn) | - 1.2(xn) | | - 0.5(xn) | - 2.1(xn) | + 1.4(xn) |
| Mean<br>Number of measures | + 0.8<br>(2) | - 2.63<br>(11) | + 2.02<br>(4) | (0) | - 6.95<br>(11) | + 0.2<br>(3) | (0) | + 0.32<br>(4) | - 3.94<br>(11) | + 3.07<br>(3) |
| Mg II | | | | | | | | | | |
| 4481.33(100) | - 9.6(x) | - 9.5(x) | - 9.2(9) | - 9.1(x) | - 7.6(x) | - 9.6(x) | - 5.4(9) | - 7.1(x) | - 7.2(x) | - 7.0(9) |
| Mean<br>Number of measures | - 9.6<br>(1) | - 9.5<br>(1) | - 9.2<br>(1) | - 9.1<br>(1) | - 7.6<br>(1) | - 9.6<br>(1) | - 5.4<br>(1) | - 7.1<br>(1) | - 7.2<br>(1) | - 7.0<br>(1) |
| Al I | | | | | | | | | | |
| 3961.53(3000) | - 0.7(1n) | + 8.6(1) | + 7.6(1) | | + 5.5(1) | +10.6(1) | | | - 4.6(1) | + 8.0(1) |
| Mean<br>Number of measures | - 0.7<br>(1) | + 8.6<br>(1) | + 7.6<br>(1) | (0) | + 5.5<br>(1) | +10.6<br>(1) | (0) | (0) | - 4.6<br>(1) | + 8.0<br>(1) |
| Si II | | | | | | | | | | |
| 3853.67(3) | | - 5.2(9) | - 1.4(5) | | - 4.4(9) | | | - 1.2(5) | - 4.8(9) | |
| 3856.03(8) | | - 4.4(x) | - 1.7(x) | | - 2.5(x) | | | + 2.1(8) | - 2.6(x) | |
| 3862.60(6) | | - 2.8(x) | - 0.8(x) | | - 3.0(x) | | | + 2.7(9) | - 3.3(x) | |
| 4128.05(8) | + 1.2(9) | - 0.1(x) | - 1.4(9) | + 2.7(9) | - 1.7(x) | + 2.0(x) | - 0.7(9) | + 2.4(9) | - 0.9(9) | - 1.2(9) |
| 4130.88(10) | + 3.8(9) | + 2.4(x) | + 1.5(x) | + 1.5(x) | - 2.5(x) | + 2.0(9) | + 1.1(9) | + 2.8(9) | - 0.2(9) | + 1.6(9) |
| Mean<br>Number of measures | + 2.5<br>(2) | - 2.02<br>(5) | - 0.76<br>(5) | + 2.1<br>(2) | - 2.82<br>(5) | + 2.0<br>(2) | + 0.2<br>(2) | + 1.76<br>(5) | - 2.36<br>(5) | + 0.2<br>(2) |
| Ca I | | | | | | | | | | |
| 4226.73(500) | + 3.8(1) | + 0.3(1) | + 7.7(1) | +11.6(0) | + 5.4(1) | | | | | |
| Mean<br>Number of measures | + 3.8<br>(1) | + 0.3<br>(1) | + 7.7<br>(1) | +11.6<br>(1) | + 5.4<br>(1) | (0) | (0) | (0) | (0) | (0) |

| 3.490 | 3.530 | 3.721 | 4.460 | 4.520 | 4.956 | 5.050 | 5.430 | Blends |
|---|---|---|---|---|---|---|---|---|
| | | -17.0(1n) | | | | | | |
| | | -18.0(3n) | -25.1(1n) | | -11.4(9n) | - 6.6(9n) | | Ti II .636(125) (Sm II .847(400)) (Cr II .14(1)) (Gd II .068(100)) |
| | | -10.8(4n) | + 0.2(3n) | | + 3.5(9n) | + 4.8(xn) | | |
| | | - 8.1(6n) | -10.8(3n) | | - 2.0(xn) | - 0.6(xn) | | |
| | | -14.4(9n) | - 6.4(6n) | | - 0.7(xn) | - 1.9(xn) | | (Gd II .69(300)) |
| | | + 1.0(xn) | + 8.7(8n) | | + 0.2(xn) | - 5.1(xn) | | (Sm II .730(600)) (Cr II .95(1)) |
| | | - 2.1(xn) | + 3.0(9n) | | - 2.3(xn) | +12.0(xn) | | |
| | | - 3.9(xn) | - 4.6(xn) | | - 6.3(xn) | - 3.9(xn) | | (Dy II .99(20)) |
| | | + 1.9(xn) | - 1.6(xn) | | - 4.4(xn) | - 2.7(xn) | | |
| + 3.8(xn) | - 6.0(xn) | - 3.1(xn) | - 0.7(xn) | - 2.4(x) | - 6.1(xn) | - 3.0(xn) | | |
| + 0.9(xn) | - 2.0(xn) | - 1.2(xn) | - 2.5(xn) | - 1.7(x) | + 1.2(x) | - 2.9(xn) | - 4.9(x) | |
| + 2.35 (2) | - 4.0 (2) | - 6.88 (11) | - 3.98 (10) | - 2.05 (2) | - 2.83 (10) | - 0.99 (10) | - 4.9 (1) | |
| - 9.0(9) | -10.6(9) | - 9.6(x) | - 5.0(x) | - 8.1(x) | -10.5(9) | - 9.4(9) | -10.6(9) | (Cr II .49(1)) (Pr II .410(10)) (Gd II .056(300)) (Tm II .273(200)) |
| - 9.0 (1) | -10.6 (1) | - 9.6 (1) | - 5.0 (1) | - 8.1 (1) | -10.5 (1) | - 9.4 (1) | -10.6 (1) | |
| | | | - 8.4(1) | - 9.9(1) | - 5.4(1) | - 0.1(2) | | |
| (0) | (0) | (0) | - 8.4 (1) | - 9.9 (1) | - 5.4 (1) | - 0.1 (1) | (0) | |
| | | - 4.0(5) | - 1.9(3) | | - 6.5(4n) | - 7.8(5) | | |
| | | - 3.7(9) | - 4.5(6) | | - 3.6(7) | - 2.1(9) | | |
| | | - 2.9(8) | - 5.7(7) | | - 3.4(5) | - 2.4(9) | | (Nd II .487(15)) |
| + 1.1(9) | - 2.3(9) | - 2.2(9) | + 1.4(5) | - 0.1(9) | + 1.3(9) | - 0.2(x) | + 6.0(9) | |
| + 0.4(9) | - 1.7(9) | - 0.9(9) | - 1.7(6) | - 3.8(9) | - 3.8(9) | - 2.8(9) | + 1.5(9) | (Ce II .706(100)) (Nd II .722(3)) (Pr II .770(40)) |
| + 0.75 (2) | - 2.0 (2) | - 3.3 (5) | - 2.48 (5) | - 1.95 (2) | - 3.2 (5) | - 5.1 (5) | + 3.75 (2) | |
| | | | | | -11.9(1) | - 6.0(0) | + 0.6(1) | Al II .809(35) Eu II .87(4?) (Nd II .992(4)) (Cr I .758(125)) |
| (0) | (0) | (0) | (0) | (0) | -11.9 (1) | - 6.0 (1) | + 0.6 (1) | |

TABLE 4-- Continued

| Laboratory λ | 0.500 | 0.691 | 0.822 | 0.981 | 1.323 | 1.460 | 1.510 | 1.642 | 2.363 | 2.580 |
|---|---|---|---|---|---|---|---|---|---|---|
| Ca II | | | | | | | | | | |
| 3933.67(600) | - 2.4(9) | - 4.3(9) | - 2.2(9) | | - 1.8(9) | - 1.4(9) | | - 3.0(8) | - 4.6(9) | + 0.4(x) |
| 3968.47(500) | + 5.8(3) | + 8.5(6) | - 2.3(1) | | + 4.5(3) | | | - 2.0(2) | - 5.2(6) | - 2.7(1) |
| Mean Number of measures | + 1.7 (2) | + 2.1 (2) | - 2.25 (2) | (0) | - 1.35 (2) | - 1.4 (1) | (0) | - 2.5 (2) | - 4.9 (2) | - 1.15 (2) |
| Ti II | | | | | | | | | | |
| 3900.54(50) | - 5.2(5n) | - 0.7(8) | - 3.6(5) | | + 2.8(5) | + 8.4(2) | | + 0.9(0) | 0.0(3) | + 4.8(3) |
| 4163.65(150) | - 4.0(3n) | - 8.4(4) | - 4.8(3) | - 0.5(2) | + 0.4(5) | + 3.7(3) | + 8.8(1) | + 1.9(3n) | - 7.1(3) | - 4.1(1) |
| 4290.23(60) | - 4.7(9) | - 4.5(x) | - 0.6(9) | + 0.4(5) | - 1.8(4n) | + 3.1(4) | + 6.3(1) | | -13.8(3n) | -15.0(2) |
| 4300.05(100) | - 2.0(3) | - 1.5(4n) | | + 5.4(2) | + 1.0(3) | + 4.7(3) | + 3.2(1) | + 1.5(3) | - 3.6(4) | - 1.7(3) |
| 4301.93(50) | - 7.2(3) | - 5.9(5) | | - 1.9(3) | + 0.1(4) | + 4.6(3) | + 2.7(1) | + 5.5(2) | - 4.5(2) | - 4.2(1) |
| 4312.87(100) | - 0.4(3) | - 2.6(4) | - 1.8(4) | + 4.9(4) | + 1.0(7) | + 6.7(4) | + 6.7(2) | + 6.0(3) | + 0.8(5) | - 0.1(4) |
| 4337.92(125) | | - 3.7(2) | - 6.5(0) | | - 0.8(0) | | | | - 5.2(1) | - 3.1(1) |
| 4367.66(25) | - 0.8(2n) | - 6.0(3) | - 2.0(2) | + 8.0(1n) | - 0.8(3) | | +14.6(1) | +13.7(0) | - 4.0(1) | - 1.8(0) |
| 4386.35(80) | - 5.9(3) | - 2.7(8n) | - 5.0(4n) | + 5.4(3) | + 3.8(4) | + 2.0(3) | + 6.4(1n) | +10.2(2) | - 4.4(1n) | - 5.7(2) |
| 4395.04(150) | - 1.6(3) | + 4.4(6) | - 1.2(6) | - 0.5(3) | + 1.6(4) | + 6.0(4) | + 3.0(1) | + 7.6(2) | - 4.2(3) | - 0.6(2) |
| 4399.77(100) | + 6.2(0) | - 5.8(4) | - 2.9(3) | + 3.9(1) | + 2.5(4) | + 7.4(2) | + 4.3(1) | + 7.9(1) | - 4.4(2) | + 6.9(0) |
| 4411.08(100) | - 5.8(1) | - 7.9(3) | - 1.6(1) | - 3.7(1) | + 5.4(2) | - 3.5(1n) | | + 4.4(0n) | -11.4(1) | -11.8(1) |
| 4443.80(125) | | - 6.5(3) | - 3.3(3) | -10.6(3n) | + 2.0(3) | + 3.8(3) | | + 4.5(1) | - 7.8(2) | - 4.3(1) |
| 4450.49(50) | - 1.8(1) | - 4.8(2) | - 3.0(2) | + 4.1(1) | - 8.0(2n) | + 1.2(3) | - 3.2(1) | + 2.6(1n) | - 9.7(2n) | - 0.8(2) |
| 4468.50(150) | - 0.7(2) | - 4.8(4) | - 4.4(3) | + 1.5(1) | + 2.6(3) | 0.0(3) | + 8.6(1n) | + 6.1(2) | - 6.0(3) | - 2.2(2) |
| 4488.32(125) | - 2.4(1) | - 2.3(3) | - 1.3(1) | + 0.4(2) | + 4.0(3) | + 6.8(3) | + 7.8(1) | + 9.2(1) | - 4.5(2) | + 0.5(1) |
| 4501.27(100) | - 5.3(3) | - 5.5(6) | - 6.1(5) | + 0.5(2) | + 5.9(4) | + 2.1(4) | + 3.0(2) | + 3.8(3) | - 8.2(3) | - 3.1(3) |
| 4529.46(40) | - 7.1(1) | - 5.3(3) | - 3.4(2) | | + 5.6(3) | +12.5(3) | + 7.2(0) | +11.2(1) | - 0.7(1n) | + 9.1(1) |
| 4533.97(150) | + 1.8(5) | + 2.2(9) | + 1.9(9) | | +.5.3(9) | + 7.2(8) | + 9.1(3) | + 9.1(5) | + 2.9(9) | + 8.5(7) |
| 4563.77(200) | + 2.8(2n) | - 6.0(3) | - 3.9(1) | | | | +11.2(1) | +11.6(1) | - 3.8(2n) | - 1.0(1) |
| 4571.98(300) | + 7.8(5) | + 1.0(9n) | + 1.0(3) | | | + 6.7(3) | + 3.2(2) | + 9.7(1) | - 0.4(2n) | + 3.8(2) |
| Mean Number of measures | - 1.91 (19) | - 3.68 (21) | - 2.76 (19) | + 1.15 (15) | + 1.72 (19) | + 4.63 (18) | + 6.05 (17) | + 6.71 (19) | - 4.76 (21) | - 1.23 (21) |
| Cr I | | | | | | | | | | |
| 4254.35(5000) | - 4.0(1) | - 0.4(2) | + 1.0(3) | + 4.1(3) | + 5.9(4) | +10.2(5) | + 6.8(2) | + 7.3(3) | +12.5(4) | + 5.9(3) |
| 4274.80(4000) | -14.5(1) | + 8.9(1) | | - 9.6(1) | +19.8(0) | | - 1.2(1) | + 4.9(1) | + 5.1(1) | - 0.8(0) |
| 4289.72(3000) | | - 9.9(1) | - 9.0(1) | -13.1(1) | - 6.9(1) | - 6.4(1) | + 0.4(0) | | | |
| Mean Number of measures | - 9.25 (2) | + 0.47 (3) | - 4.0 (2) | - 6.2 (3) | + 6.27 (3) | + 1.9 (2) | + 2.0 (3) | + 6.2 (2) | + 8.8 (2) | + 2.55 (2) |

| 3.490 | 3.530 | 3.721 | 4.460 | 4.520 | 4.956 | 5.050 | 5.430 | Blends |
|---|---|---|---|---|---|---|---|---|
| + 0.2(9) | - 0.3(8) | - 2.9(5) | - 1.8(4) | - 2.1(4n) | - 3.9(7n) | - 5.3(9) | | (Fe I .605(200)) (Ce II .731(60)) |
| | | + 4.5(2) | -13.5(3) | | - 9.6(8) | - 7.5(8) | | (Dy II .395(1000)) |
| + 0.2 (1) | - 0.3 (1) | + 0.8 (2) | - 7.65 (2) | - 2.1 (1) | - 6.75 (2) | - 6.4 (2) | (0) | |
| | | - 5.2(2n) | - 7.0(3) | | - 4.5(3) | - 2.0(6) | | (Fe I .519(60)) |
| + 5.5(0) | + 1.9(1n) | | - 7.3(2) | - 9.7(5) | - 3.4(3) | - 1.2(5) | + 0.6(5) | (Ce II .516(20)) (Cr I .620(100)) |
| | -10.8(1n) | - 8.0(1) | -15.7(4n) | -17.5(7n) | -14.5(5) | -14.9(5) | - 9.6(9) | Ce II .938(300) Gd II .884(80) |
| + 6.6(1) | + 5.2(1) | + 9.6(2) | - 6.6(3) | - 4.0(7) | - 3.7(3) | - 0.2(4) | + 6.7(5n) | (A I .100(1200)) |
| - 3.1(1n) | - 4.9(1) | -13.2(1) | - 3.9(3) | - 7.0(3n) | - 7.2(2) | - 1.4(3n) | - 5.6(6) | (Pr II .100(60)) (Zr II .81(5)) |
| + 6.5(1) | + 2.3(2) | + 2.2(2n) | | + 1.8(5) | + 3.5(4n) | | + 4.5(4) | (Fe II .034(1)) |
| | | | | | - 3.9(2n) | +10.4(0) | | Ce II .777(125) (La II .78(10)) (Zr II .63(5)) |
| | | -15.6(1) | - 5.1(1) | - 2.4(3) | - 1.0(2n) | +13.0(2) | + 1.4(2n) | Fe I .582(100) (Eu II .54(3)) |
| -12.2(1n) | | -11.4(1) | - 5.3(1) | -10.6(6) | - 8.9(4) | - 4.0(4) | - 1.4(5) | (Ce II .835(15)) |
| | + 2.5(2) | + 0.3(1n) | - 4.4(1n) | - 9.1(7) | - 3.4(5n) | - 6.5(4) | - 2.3(3) | Fe I .286(80) Dy II .98(40) (Pr II .005(15)) (Tb II .92(3)) |
| | + 3.8(1) | +10.6(1) | - 9.0(1) | - 5.9(3) | - 6.9(1) | + 0.3(2n) | - 0.3(2) | |
| | + 0.3(0) | -15.0(0) | - 6.7(1) | + 4.1(1) | + 5.6(1) | + 6.5(1) | - 9.1(2) | Nd II .052(150) La II .21(25) (Gd (II?) .159(?)) |
| | - 6.1(1) | +10.4(1) | - 4.2(1) | - 6.4(2) | + 0.1(2n) | + 3.0(2) | + 2.2(1) | Ce II .743(187) (La II .94(20)) |
| + 0.7(0) | - 9.1(1) | -14.3(1) | - 8.4(1) | -10.5(3) | -12.7(2) | -10.0(2) | - 2.6(2) | Pr II .214(40) |
| + 7.2(1) | + 4.5(2) | - 1.7(1n) | + 4.0(1) | - 2.4(3) | + 3.2(3n) | - 1.1(3) | + 1.3(3) | (Pr II .712(150)) |
| + 7.5(0) | -12.0(0) | + 8.2(0) | + 2.0(1) | - 4.5(3) | + 1.1(4) | + 1.1(5) | + 5.1(2) | Eu II .25(15) |
| - 2.1(1) | -10.0(3) | -12.8(2) | - 6.9(3) | - 6.7(5) | - 6.8(6) | - 4.7(6) | - 1.9(3) | |
| + 3.0(1) | + 9.1(1) | + 8.7(1n) | + 6.2(1) | + 1.6(3) | + 2.9(2n) | + 8.8(2) | +12.0(1) | (Fe II .56(pr)) (Tm II .376(80)) |
| + 6.1(3) | + 7.1(4) | + 7.3(5) | - 8.7(1) | + 3.2(5) | - 3.6(8n) | - 0.8(5n) | + 3.6(7) | Fe II .166(2) (Pr II .154(60)) (P II .81(15)) (Mg II .26(4)) |
| + 4.8(1) | + 7.6(1) | -14.7(0) | - 3.7(1) | - 3.4(3) | + 1.8(3) | + 1.0(3) | - 1.2(3) | (Tb II .68(20)) |
| | + 0.6(1) | -15.3(1) | + 3.2(1n) | - 1.9(5) | -13.6(4) | - 1.1(5) | + 3.1(3) | |
| + 2.54 (12) | - 0.05 (17) | - 3.68 (19) | - 4.61 (19) | - 4.81 (19) | - 3.61 (21) | - 0.19 (20) | + 0.34 (19) | |
| - 2.3(3) | + 1.2(3) | + 1.3(3) | +13.0(4) | +12.3(4) | +11.9(2n) | +19.4(2n) | - 0.8(1n) | Pr II .420(20) |
| - 7.4(0) | -11.6(1) | + 4.1(2n) | + 3.6(1n) | + 9.3(1) | + 8.1(0) | +20.6(0) | - 8.5(1) | Eu II .86(5) (Nd II .083(10)) (Gd II .033(4)) |
| -13.6(0) | | - 5.2(1) | | | | | | Ce II .454(25) |
| - 7.78 (3) | - 5.2 (2) | + 0.07 (3) | + 8.3 (2) | +10.8 (2) | +10.0 (2) | +20.0 (2) | - 4.65 (2) | |

TABLE 4 -- Continued

| Laboratory λ | 0.500 | 0.691 | 0.822 | 0.981 | 1.323 | 1.460 | 1.510 | 1.642 | 2.363 | 2.580 |
|---|---|---|---|---|---|---|---|---|---|---|
| Cr II | | | | | | | | | | |
| 3712.95(50) | | -10.6(2) | | | - 6.2(x) | | | | + 2.3(6) | |
| 3723.40(15) | | | | | - 9.1(0) | | | | + 7.7(1) | |
| 3727.36(40) | | -10.0(2) | | | - 3.3(3) | | | | +10.4(2) | |
| 3738.38(25) | | -13.2(2) | | | - 7.5(7) | | | | - 2.0(8) | |
| 3754.58(20) | | -12.2(1) | | | - 3.9(2) | | | | + 4.9(7) | |
| 3801.21(10) | | -11.8(0) | | | - 4.4(0) | | | | + 3.7(1) | |
| 3865.59(75) | | - 6.1(5) | - 7.2(5) | | - 3.6(5) | | | + 1.5(3) | + 7.4(3) | |
| 3905.65(25) | -11.8(9) | -10.8(7) | - 6.5(5) | | - 4.9(9) | - 0.8(6) | | - 1.9(6) | - 3.8(3n) | - 6.4(3n) |
| 4003.33(25) | | -12.6(3) | -11.1(3) | | - 4.2(3) | - 0.5(3) | | - 5.1(3) | - 2.0(1) | -10.9(1n) |
| 4012.47(30) | - 9.6(9) | - 8.1(x) | - 7.1(8) | - 3.7(9) | - 0.8(9) | + 2.8(9) | + 5.0(3) | + 4.6(5) | +11.1(4) | - 1.2(5) |
| 4038.03(25) | - 8.6(5) | - 8.9(5) | - 7.9(3) | - 4.8(2) | - 5.6(5) | - 1.6(3) | - 1.5(2) | - 0.4(4) | - 5.0(3) | + 7.5(3) |
| 4049.16(18) | | -10.2(3) | -13.7(2) | | - 9.3(4n) | + 0.7(3) | | | + 0.2(1) | +14.3(0) |
| 4051.97(12) | -11.3(2) | - 8.9(3) | -10.8(3) | -10.2(2) | - 9.0(5) | + 0.7(3) | + 4.7(1) | - 3.2(3) | + 1.4(2) | |
| 4054.18(8) | | -12.1(3) | -14.2(3) | - 9.7(2) | -10.2(7) | - 9.2(6) | - 6.1(2) | - 8.0(5) | -11.8(2n) | |
| 4070.90(10) | -16.7(5) | -14.7(3n) | -17.8(4) | -10.9(3) | - 8.2(4) | - 6.5(6) | - 4.2(1) | - 4.9(3) | - 2.9(3) | - 7.7(2) |
| 4082.30(10) | | -11.8(1) | -11.4(1) | - 9.1(1) | - 6.5(4) | - 2.5(3) | + 0.4(0) | - 2.2(3) | + 3.9(2) | + 8.7(0) |
| 4098.44(8) | -13.4(1) | - 9.4(1) | - 9.7(0) | | - 5.7(2) | - 5.3(0) | | | + 4.3(2) | + 3.7(1) |
| 4111.01(18) | | -12.0(3) | - 8.5(2) | -10.2(1) | - 4.2(5) | - 2.2(3n) | - 9.3(1n) | + 2.6(3) | - 0.6(2) | - 2.9(1) |
| 4113.24(5) | - 8.5(3) | - 7.6(3) | - 6.8(2) | - 0.2(2) | - 5.5(4) | - 4.2(3) | - 3.4(1) | - 1.1(1) | + 1.9(1) | + 8.3(1) |
| 4145.80(25) | -12.3(1) | -10.3(3) | - 8.6(2) | -10.2(2) | - 4.3(4) | - 3.0(3) | - 0.4(1) | + 2.2(3) | + 2.5(2) | -13.3(0) |
| 4179.46(12) | - 7.4(3) | - 8.4(5) | - 8.0(4) | - 4.0(3) | - 5.1(8) | - 1.2(4) | - 1.4(1) | + 1.6(3) | + 2.8(3) | + 3.7(1) |
| 4224.85(20) | | - 7.8(2) | - 4.8(2) | - 0.6(2) | - 3.2(5) | + 2.8(2) | 0 (1) | + 1.4(3) | + 8.7(2) | + 6.2(0) |
| 4242.38(30) | - 9.5(4) | -11.4(5) | - 9.1(7) | - 6.1(8) | - 5.6(9) | - 1.1(7) | - 0.6(9) | - 7.1(7) | + 5.0(5) | + 1.6(4) |
| 4252.66(10) | - 9.3(1) | -13.3(4) | - 9.9(7) | - 7.0(3) | - 6.0(5) | - 2.9(7) | - 2.9(3) | + 1.9(3) | + 4.1(3) | - 1.6(3) |
| 4256.16(5) | | -14.0(2) | -11.3(2) | | - 5.0(2) | | - 7.0(2n) | - 4.1(3n) | + 2.9(3) | -11.1(2) |
| 4261.91(20) | + 2.1(4n) | - 6.8(4) | - 4.8(5) | - 1.2(5) | - 3.2(9) | + 3.2(9) | + 4.1(5) | + 5.6(6) | + 4.5(8) | + 5.8(5) |
| 4269.28(10) | - 8.3(1) | - 8.9(4) | - 8.2(3) | - 0.4(2) | - 2.1(4) | + 0.8(3) | - 2.0(2) | + 7.4(3) | + 4.6(3) | - 0.5(3) |
| 4275.57(30) | - 8.7(3) | - 9.6(4) | -10.5(5) | - 5.0(3) | - 6.1(5) | - 1.0(4) | + 0.4(3) | + 4.1(3) | + 3.5(3) | - 1.0(1) |
| 4284.21(20) | | -10.0(2) | - 7.4(2) | - 4.6(2) | - 5.8(3) | - 1.8(3) | - 4.2(2) | - 3.2(2) | + 6.4(3) | - 3.4(2n) |
| 4555.03(20) | - 2.5(0) | - 8.3(4) | -13.7(2) | | | - 7.2(4) | - 7.0(1) | - 0.3(4) | + 1.0(5) | - 4.9(2) |
| 4558.66(100) | - 7.1(3n) | - 6.1(9) | - 5.3(5) | | | - 1.4(9) | + 0.9(3) | + 3.2(8) | + 2.7(9) | - 0.9(4) |
| 4565.78(10) | - 5.4(1) | - 9.4(4) | -10.3(2) | | | - 1.0(4) | - 2.0(1) | - 1.9(3) | - 1.7(5) | - 3.4(1) |
| 4588.22(75) | + 6.5(3) | -10.0(9) | -10.9(3) | | | - 0.3(5) | + 0.2(2) | + 2.6(4) | + 2.2(6) | + 0.7(3) |
| 4592.06(20) | + 9.3(1) | - 8.0(8) | - 9.5(4) | | | - 1.8(4) | + 0.5(1) | + 3.9(3) | + 0.2(5) | + 1.8(2) |
| 4616.66(18) | | - 7.6(6) | -12.3(3) | | | - 6.4(6) | | | - 3.0(9) | - 6.3(3) |
| 4618.83(35) | | +11.3(3) | +17.8(0) | | | + 0.8(5) | | | + 4.3(3) | + 0.3(2) |
| 4634.07(25) | | - 9.9(8) | - 8.9(5) | | | - 1.0(6) | | | + 1.9(4) | - 0.8(2) |
| Mean<br>Number of<br>comparisons | - 6.97<br>(19) | - 9.43<br>(36) | - 8.66<br>(31) | - 5.76<br>(17) | - 5.48<br>(29) | - 1.76<br>(24) | - 1.58<br>(23) | - 0.03<br>(26) | + 2.26<br>(37) | - 0.49<br>(28) |

| 3.490 | 3.530 | 3.721 | 4.460 | 4.520 | 4.956 | 5.050 | 5.430 | Blends |
|---|---|---|---|---|---|---|---|---|
| | | - 5.9(5) | - 0.2(2) | | + 3.5(2) | | | |
| | | - 4.6(1) | + 0.7(1) | | + 6.8(0) | + 7.2(0) | | (Ti II .631(15)) (Gd II .24(8)) (Gd II .69(20)) (Nd II .506(50)) |
| | | + 3.0(1) | + 6.1(1) | | + 9.5(2) | | | V II .351(1000) (O II .30(50)) |
| | | - 5.4(3) | + 0.5(2) | | + 4.3(1) | + 9.1(1) | | (Fe I .308(100)) (Zr II .13(5)) |
| | | - 3.0(4) | + 1.2(3) | | + 5.2(4) | + 9.4(3) | | |
| | | - 3.7(1) | | | + 7.5(0) | + 9.6(0) | | Gd II .29(400) |
| | | - 4.2(4) | - 0.7(5) | | + 7.2(3) | + 7.1(4) | | Fe I .526(600) |
| - 6.6(3) | - 7.9(2) | - 6.7(3) | + 0.2(4) | | + 6.1(2) | + 3.9(3) | | (Si I .528(20)) (Dy II .56(2)) |
| -10.3(2) | - 6.2(2) | - 8.4(2) | - 0.7(1) | - 1.4(2) | + 6.3(1) | + 1.6(1) | | |
| | - 0.3(9) | + 1.0(5) | + 8.8(8) | + 4.9(5n) | + 8.8(3) | + 7.8(8) | | Ce II .389(300) Fe II .467(1) (Tb II .46(4)) |
| | | - 4.6(3) | - 1.9(2) | - 1.8(3) | + 4.4(1) | -10.6(3) | | Gd II .897(1200) (Nd II .124(20)) (Pr II .154(20)) |
| | + 4.2(0) | -15.3(2n) | | + 6.7(2) | -15.3(2) | -16.7(1) | | |
| - 5.4(2) | - 5.2(3) | - 7.3(3) | + 3.8(3) | + 0.4(4) | + 5.4(3) | +10.1(2) | | (Tb II .87(30)) |
| -14.1(2) | -13.0(3) | -11.0(3) | - 0.4(1) | - 2.8(3) | + 2.2(1) | | -13.2(3) | |
| - 9.9(2) | - 7.9(3) | - 6.0(3) | + 3.5(2) | - 0.3(3) | + 8.3(3) | + 4.6(1) | -27.7(5) | (Tb II .58(10)) |
| - 2.8(1) | - 9.7(1) | - 3.3(2) | + 8.0(1) | + 1.4(2) | + 6.8(1) | +12.8(1) | | (Tb II .23(4)) |
| - 1.2(1) | - 2.8(1) | - 4.5(0) | - 0.2(1) | + 3.5(3) | + 8.2(3) | + 6.4(3) | | Gd II .606(3000) (Pr II .410(10)) |
| - 6.1(2) | - 7.7(2) | - 2.6(2) | + 3.4(1) | + 6.8(3) | + 7.1(5) | +14.4(2) | | (Mn I .903(80)) (Eu II .07(5)) |
| - 3.6(1) | - 1.2(0) | - 5.3(1) | + 1.4(0) | + 2.4(1) | + 9.5(1) | +15.6(0) | - 5.7(2) | (La II .28(40)) |
| - 7.3(2) | - 3.7(2) | - 3.2(3) | + 3.9(2) | + 1.5(5) | + 5.1(3) | +10.2(2) | + 9.5(1) | |
| - 2.7(2) | - 4.6(3) | - 3.0(3) | - 3.4(2) | - 2.7(6) | + 1.4(3) | + 8.0(3) | +11.0(0n) | Pr II .421(150) (Cr I .257(100)) (Eu II .37(4)) |
| + 0.5(1) | - 4.5(1) | - 6.0(2) | + 5.8(2) | + 3.7(4) | +10.2(2) | +12.0(2) | | (Nd II .847(8)) |
| - 4.3(7) | - 5.0(7) | - 5.0(7) | + 2.2(3) | + 0.9(6) | + 1.6(2) | + 9.0(2) | - 3.1(5) | (Mg II .47(4)) (Mn II .30(2)) (Tb II .57(12)) |
| - 7.2(2) | | - 6.8(3) | + 0.4(3) | + 1.7(6) | + 4.0(3) | + 6.6(3) | +10.1(3) | (Nd II .437(40)) |
| | -12.7(3) | - 9.7(2n) | + 1.8(2) | - 0.3(5) | + 4.6(3) | + 6.5(3) | +11.4(4n) | (Ti I .036(80)) (Ce II .156(5)) (Nd II .239(8)) (Dy II .97(1)) (Dy II .204(3)) |
| - 0.4(5) | - 0.7(8) | - 2.1(7) | + 5.6(5) | + 3.7(x) | + 5.4(6) | + 9.3(8) | +11.5(8) | Gd II .092(2500) (Nd II .837(20)) (Pr II .796(15)) |
| - 4.9(1) | - 3.9(4) | - 1.2(4) | + 5.6(2) | + 3.5(5) | + 6.6(3) | + 7.2(3) | +10.6(2) | |
| - 2.2(2) | - 1.4(2) | - 3.7(3) | + 3.7(3) | + 3.1(4) | + 4.8(2) | + 7.8(2) | +12.4(2) | (La II .641(100)) (Ce II .561(25)) |
| | - 3.8(5) | - 0.2(4) | + 8.9(4) | + 6.9(8) | +11.3(3n) | +15.0(3n) | +19.7(3) | (Mn I .084(40)) |
| - 7.8(4) | -13.3(3) | - 8.0(4) | + 1.0(3) | + 1.6(9) | + 4.7(3) | + 7.1(3) | | Gd II .989(50) |
| - 2.0(8) | - 2.4(7) | - 1.6(9) | + 3.0(9) | + 2.6(9) | + 6.5(5) | + 6.4(7) | + 7.5(2) | (Cr II .83(pr)) |
| + 1.2(1) | - 3.1(2) | - 9.0(4) | + 3.4(3) | + 1.9(5) | + 5.4(3) | +11.7(2) | | Ce II .842(50) (Eu II .57(5)) |
| - 0.7(7) | - 7.0(4) | - 3.3(5) | + 1.4(5) | + 1.0(6) | + 3.4(3) | + 3.3(4) | -10.2(2) | Dy II .931(40) (P II .90(300)) (Al II .194(30)) |
| - 1.4(5) | - 5.4(4) | - 5.2(7) | + 2.2(4) | - 0.6(4) | + 7.4(4) | + 6.7(3) | - 6.4(2) | |
| - 4.7(3) | - 9.9(3) | | + 1.4(4) | - 3.4(4) | + 3.8(3) | + 6.0(3) | | |
| - 1.4(4) | - 2.5(4) | - 5.1(5) | + 0.1(3) | + 1.1(5) | + 4.0(5) | + 3.0(7) | | |
| - 2.0(5) | - 5.0(3) | - 5.7(5) | + 3.8(5) | + 0.3(4) | + 1.1(3) | + 7.4(2) | | |
| - 4.69 (45) | - 5.24 (28) | - 4.31 (36) | + 2.40 (35) | + 1.60 (29) | + 5.22 (37) | + 6.63 (34) | + 2.49 (15) | |

TABLE 4 -- Continued

| Laboratory λ | 0.500 | 0.691 | 0.822 | 0.981 | 1.323 | 1.460 | 1.510 | 1.642 | 2.363 | 2.580 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Mn I** | | | | | | | | | | |
| 4034.49(250) | | + 1.5(0) | + 7.8(1) | | | -11.4(1) | - 8.1(1) | | | |
| 4041.36(100) | + 9.1(2) | + 5.9(1) | + 7.6(1) | +12.2(1) | | + 9.6(0) | | | | + 5.6(0) |
| Mean<br>Number of measures | + 9.1<br>(1) | + 3.7<br>(2) | + 7.7<br>(2) | +12.2<br>(1) | (0) | - 0.9<br>(2) | - 8.1<br>(1) | (0) | (0) | + 5.6<br>(1) |
| **Mn II** | | | | | | | | | | |
| 4206.43(2) | - 8.9(3) | -11.0(3) | - 9.6(3) | - 4.6(2) | - 8.0(3) | - 3.6(1) | + 2.5(1) | - 2.9(1) | + 0.1(1) | + 6.3(1) |
| 4253.02(2) | - 2.1(0) | - 4.7(1) | - 5.2(0) | - 0.9(0) | - 1.3(1) | + 4.9(0) | | + 4.8(1) | | |
| 4259.26(2) | - 7.2(1n) | - 5.8(2n) | + 1.3(3n) | + 3.4(2) | - 5.0(2n) | - 0.6(3) | | + 5.8(2) | - 4.1(3) | - 5.4(3) |
| 4419.78(2) | - 7.7(1n) | | | - 7.1(1n) | | -11.8(1) | - 9.4(0) | | | -12.4(1) |
| 4510.21(3) | - 6.3(1) | | | - 1.7(0) | | + 2.2(1) | | | | - 5.8(0) |
| Mean<br>Number of measures | - 6.44<br>(5) | - 7.17<br>(3) | - 4.5<br>(3) | - 2.18<br>(5) | - 4.77<br>(3) | - 1.78<br>(5) | - 3.45<br>(2) | + 2.57<br>(3) | - 2.0<br>(2) | - 4.33<br>(4) |
| **Fe I** | | | | | | | | | | |
| 3763.79(500) | | - 8.9(2) | - 5.3(1) | | - 5.1(4) | | | + 5.4(1) | + 3.1(3) | |
| 3787.88(500) | | -10.4(1n) | - 4.5(1) | | - 6.8(2) | | | -10.6(1) | - 1.0(1) | |
| 3812.96(400) | | -21.6(0n) | - 8.6(3) | | -12.3(1) | | | + 4.3(1) | -10.5(1) | |
| 3815.84(700) | | - 7.0(5) | - 8.2(4) | | - 4.5(5) | | | - 1.1(2) | - 3.9(3) | |
| 3820.43(800) | | - 5.3(5n) | - 2.5(3) | | - 4.7(6) | | | - 1.4(4) | - 4.2(6) | |
| 3841.05(500) | | - 4.8(2) | - 5.6(2n) | | - 0.6(3) | | | + 1.4(1) | - 3.8(2) | |
| 3856.37(500) | | | | | - 2.3(1) | | | + 5.4(1) | + 9.6(1) | |
| 3859.91(1000) | | - 8.7(5) | - 5.8(4) | | - 1.2(3) | | | + 4.3(2) | - 1.8(3) | |
| 3902.95(500) | - 0.2(0) | - 3.9(2) | - 4.8(1) | | - 0.2(3) | + 1.2(1) | | - 5.2(1) | - 0.6(1) | - 5.1(0n) |
| 3930.30(600) | -11.3(2) | + 2.4(3) | - 6.4(2) | | + 0.7(2) | + 3.1(3) | | + 3.7(3) | - 0.7(3) | -13.1(3) |
| 4005.25(250) | -14.2(3) | -12.1(2) | -12.5(3) | | -12.1(2n) | + 7.3(0n) | | - 5.2(2) | -14.0(1) | |
| 4045.82(400) | -11.4(6) | -10.7(7) | -10.7(5) | - 4.4(4) | -11.8(5) | - 1.7(4) | - 0.4(2) | - 4.1(3) | - 3.8(5) | + 0.7(3) |
| 4063.60(400) | - 7.7(5) | - 6.4(7) | - 8.4(5) | - 1.7(3) | - 6.7(5) | + 0.2(4) | - 0.1(2) | - 1.4(4) | - 6.0(4) | - 4.7(3) |
| 4071.74(300) | -10.8(1) | - 4.4(2) | - 8.2(2) | - 1.1(2) | - 2.6(4) | - 0.1(4) | + 4.6(1) | + 1.0(3) | - 3.1(4) | - 1.6(3) |
| 4132.06(300) | - 1.9(0) | - 7.8(1) | - 8.2(1) | - 3.8(0n) | - 6.0(1) | + 7.1(0) | +11.8(1) | - 8.9(0) | | |
| 4143.42(200) | | - 6.9(0) | | -13.9(2) | + 8.2(0) | - 7.8(2) | - 7.2(1) | - 5.4(1) | +17.0(0) | |
| 4143.87(400) | - 7.7(2) | - 6.5(5) | - 1.9(3) | + 0.1(2) | + 0.3(4) | + 4.4(2) | + 2.0(1) | + 3.5(1) | + 4.2(1) | + 5.3(0) |
| 4147.67(200) | | -15.0(2) | | - 6.8(0) | - 8.2(1) | | | | | |
| 4187.04(250) | +15.7(2n) | + 4.2(1) | +18.6(0) | | + 1.6(1) | + 7.7(0) | | + 8.4(1) | + 1.7(1) | + 8.4(0) |
| 4199.10(300) | | - 6.6(1) | - 5.4(1) | | - 3.1(2) | - 3.9(0) | - 4.8(1) | | | +12.6(0) |
| 4202.03(400) | - 6.5(1) | - 7.1(2) | - 8.9(3) | - 6.0(2) | - 5.2(3) | - 3.1(1) | - 6.8(1) | - 5.4(1) | -10.3(1) | -11.6(0) |
| 4210.35(300) | - 6.0(1) | -10.7(1) | - 8.5(1) | -13.6(0) | - 9.0(1) | - 7.1(0) | - 7.9(0) | - 2.4(1) | -10.8(1n) | |
| 4219.36(250) | | | | - 1.7(0) | - 4.0(1n) | | - 4.0(1n) | + 5.5(0) | | - 8.4(0) |
| 4227.43(300) | - 9.4(4) | -11.4(4) | - 7.2(5) | - 6.4(5) | - 3.7(5) | + 3.5(2) | - 0.4(3) | - 2.0(3) | - 3.3(2n) | + 2.1(2) |
| 4235.94(300) | - 7.0(1) | - 5.9(2) | - 5.0(2) | - 1.6(1) | + 0.4(2) | + 3.2(0) | + 6.2(0) | | + 0.8(1) | |
| 4260.48(400) | - 1.8(1) | - 5.9(2) | - 5.6(3) | - 0.1(2) | + 0.5(3) | + 0.6(2) | + 0.4(2) | + 4.1(3) | - 0.8(2) | -11.4(2) |

| 3.490 | 3.530 | 3.721 | 4.460 | 4.520 | 4.956 | 5.050 | 5.430 | Blends |
|---|---|---|---|---|---|---|---|---|
| | - 0.3(0) | - 8.4(1) | | | | -14.7(2n) | - 2.8(0) | |
| | +13.4(0) | | - 6.6(1) | -11.1(3) | - 0.3(3) | + 2.2(2) | + 4.2(1) | |
| (0) | + 6.55 (2) | - 8.4 (1) | - 6.6 (1) | -11.1 (1) | - 0.3 (1) | - 6.25 (2) | + 0.7 (2) | |
| +13.6(0) | | - 6.8(1n) | + 1.5(0) | + 1.7(1) | - 4.4(1) | + 3.9(1) | | Dy II .544(40) |
| | + 2.3(0) | | | | | | | (La II .92(4)) |
| - 9.9(1) | -10.2(2n) | - 3.8(3) | + 3.5(3) | + 4.0(9) | + 1.8(3n) | +12.2(3) | +10.8(7) | A I .361(1200) (Eu II .22(3)) |
| | -13.0(1) | | | | + 0.3(1) | | - 8.2(2) | |
| | | | | | + 3.2(1) | | -11.0(4) | |
| + 1.85 (2) | - 6.97 (3) | - 5.3 (2) | + 2.5 (2) | + 2.85 (2) | + 0.23 (4) | + 8.05 (2) | - 2.80 (3) | |
| | | -11.3(2) | - 4.1(1) | | -12.3(1) | - 9.9(1) | | |
| | | - 5.6(0) | - 1.9(0) | | + 8.8(1) | -14.0(1) | | |
| | | +17.7(0) | + 6.0(0) | | +11.3(3) | +11.8(3) | | |
| | | + 0.2(4) | | | | - 2.2(1n) | | Cr II .77(2) (Ce II .831(250)) |
| | | - 3.5(3) | - 1.2(3) | | + 7.5(2) | + 5.0(2n) | | Cr II .48(2) |
| | | - 1.6(2) | + 3.4(1n) | | + 5.1(1) | + 8.9(1) | | (Pr II .006(60)) |
| | | | + 4.5(1) | | +10.8(1) | +13.1(1) | | |
| | | - 2.2(2) | - 0.6(2) | | + 7.4(2) | + 8.9(3) | | |
| | | + 0.1(1) | + 1.5(1) | | + 2.5(2) | + 8.2(1) | | (Mo I .963(1000)) |
| - 0.9(3) | + 2.6(3) | + 3.2(3) | | + 6.5(5) | | | | (Fe II .31(pr)) |
| - 2.5(1) | - 4.8(1) | + 0.8(1n) | + 3.0(1) | + 3.6(1) | + 9.7(1) | +10.1(1) | | |
| - 2.4(3) | - 4.4(3) | - 3.1(3) | + 1.8(2) | + 2.5(3) | + 5.8(4) | + 3.6(2) | | (A I .966(150)) |
| - 3.2(2) | - 0.1(2) | - 6.0(2) | + 3.4(2) | + 5.5(4) | + 6.4(2) | + 8.3(2) | -12.0(4) | Gd II .59(200) (Mn I .528(100)) |
| 0 (2) | - 3.1(2) | - 0.6(2n) | + 6.7(2) | + 1.2(4) | + 2.3(4) | +10.1(3) | + 7.3(0) | Ce II .814(150) (Ce II .814(150)) |
| | | - 3.8(0) | | -21.6(0) | | | | (A II .73(80)) (La II .74(5)) |
| | | - 1.7(1) | + 1.7(1) | + 8.5(1) | + 9.8(2) | +10.3(2) | | |
| - 1.8(0) | + 0.1(1) | | + 3.3(1) | + 3.0(2) | + 8.2(1) | + 6.8(1) | -11.6(2) | (La II .77(15)) |
| - 6.4(0) | | - 2.8(0) | | | - 7.6(1) | +11.2(1) | +10.9(0) | |
| | | | +11.4(1) | + 9.4(3) | + 9.2(1) | + 9.0(1) | +10.6(2) | |
| | + 0.6(0) | - 9.7(1) | | + 0.3(1) | + 0.1(1) | + 6.9(1) | | (Nd II .099(10)) (Cr II .02(pr)) |
| - 2.7(1) | | - 7.4(1) | + 3.8(1) | + 7.5(1n) | + 6.5(2) | - 1.9(0) | | |
| | - 3.1(0) | - 5.4(1) | + 6.2(1) | + 1.7(2) | + 7.8(1) | + 9.9(1) | + 8.4(1) | Sm II .352(150) (La II .22(50)) |
| + 1.8(0) | + 3.6(1) | + 0.8(1) | | + 3.6(0n) | + 8.8(1) | | - 7.6(1) | |
| - 4.2(1) | - 5.0(2) | - 0.1(1n) | | + 4.8(1n) | + 8.4(1) | + 3.2(0n) | - 9.3(3) | Eu II .40(6) (Al II .500(30)) (Al II .406(8)) |
| | | - 5.3(1) | + 2.3(1) | + 0.6(2) | + 3.8(1) | +11.3(0) | -12.0(1) | Gd II .88(60) |
| - 4.8(1) | - 7.6(1) | - 6.0(2) | + 5.1(1) | - 4.4(3) | - 2.9(2) | + 6.6(1) | - 0.1(3) | |

TABLE 4 -- Continued

| Laboratory λ | 0.500 | 0.691 | 0.822 | 0.981 | 1.323 | 1.460 | 1.510 | 1.642 | 2.363 | 2.580 |
|---|---|---|---|---|---|---|---|---|---|---|
| Fe I - Continued | | | | | | | | | | |
| 4271.76(1000) | + 4.4(1n) | - 6.0(2) | - 6.8(3) | + 0.5(3) | - 0.8(3) | + 4.2(2) | + 6.1(1) | + 7.6(3) | - 1.0(1n) | + 5.4(1) |
| 4282.41(600) | - 2.2(3) | - 4.8(4) | - 2.2(3) | + 2.4(3) | + 1.7(3) | + 7.3(3) | + 3.5(1) | + 8.5(1) | + 5.5(1) | + 1.0(1) |
| 4299.24(500) | - 8.7(1) | - 3.5(1n) | | - 3.7(0) | +12.8(1) | - 1.4(2) | + 8.3(0) | - 5.4(1) | + 7.3(1) | + 1.0(0) |
| 4383.55(1000) | | - 8.3(5) | - 8.5(4) | - 5.3(2) | - 4.6(4) | - 1.7(3) | - 7.3(2) | - 4.6(3) | - 1.8(3) | - 1.2(3) |
| 4404.75(1000) | - 3.1(4) | - 7.2(9) | - 4.1(9) | - 1.6(5) | - 2.4(9) | - 0.5(5) | - 1.3(3) | + 2.1(4) | - 7.6(4) | - 0.1(3) |
| 4415.12(600) | | - 5.2(1) | - 1.5(2) | +12.4(0) | - 0.3(2) | -13.4(0) | | + 9.8(0) | - 1.8(2) | -10.5(0) |
| 4427.31(500) | - 4.2(0) | + 3.2(0) | | | | -13.2(0) | | + 3.0(1) | | - 2.6(0) |
| 4442.34(400) | | | - 9.7(1) | + 6.7(1) | - 4.7(0) | | | | - 7.3(1) | |
| 4476.02(500) | + 3.8(0) | -10.0(1) | - 6.4(1) | + 5.0(0) | + 0.6(1) | | | + 4.1(0) | - 7.4(1) | -12.1(0) |
| 4528.62(600) | -12.5(1) | | | + 0.9(1) | | - 6.0(1) | + 3.4(1) | + 4.2(1) | | + 0.8(1) |
| 4602.94(300) | | + 1.2(1) | | | | -12.3(0) | | | - 0.1(0) | |
| Mean<br>Number of measures | - 4.89<br>(21) | - 6.73<br>(33) | - 5.61<br>(29) | - 1.99<br>(22) | - 2.83<br>(34) | - 0.90<br>(25) | + 0.32<br>(19) | + 0.72<br>(32) | - 1.82<br>(31) | - 2.14<br>(21) |
| Fe II | | | | | | | | | | |
| 3824.91(4) | | - 6.7(4) | - 4.2(2) | | + 0.4(3) | | | + 8.9(1) | - 1.6(2) | |
| 3827.08(4) | | - 6.5(3) | - 7.9(1) | | - 3.7(3) | | | + 0.8(1) | - 2.5(3n) | |
| 3845.18(4) | | - 6.8(3) | - 5.1(1) | | - 0.6(3) | | | + 6.7(0) | + 8.3(2) | |
| 3906.04(5) | - 5.6(8) | - 8.0(5) | - 2.8(3) | | - 0.8(5) | + 2.8(3) | | + 4.5(3) | + 1.2(3n) | + 1.3(3n) |
| 3938.97(4) | -10.0(6) | - 8.3(6) | - 6.6(5) | | + 0.9(6) | + 0.2(5) | | + 0.1(4) | - 2.1(4) | + 0.6(3) |
| 3960.90(3) | - 5.6(3) | - 1.9(3) | - 3.7(2) | | + 0.6(3) | + 2.3(1) | | - 0.2(1) | - 3.6(2) | - 0.3(3) |
| 3974.16(3) | - 9.4(1) | - 8.3(2) | - 8.6(1) | | - 9.0(1n) | - 9.7(0n) | | | - 4.5(2n) | |
| 4024.55(5) | - 6.9(5) | - 5.4(5) | - 5.2(5) | - 0.2(3) | - 0.4(5) | + 2.2(4) | - 2.4(1) | - 1.9(5) | - 3.4(3) | - 2.7(5) |
| 4048.83(3) | - 9.6(4) | - 4.5(4) | - 8.7(2) | - 0.4(3) | -13.6(3n) | + 0.7(4) | + 4.4(1) | | - 0.8(2) | + 4.4(3) |
| 4122.64(4) | - 6.1(2) | - 3.6(5) | -11.4(4) | + 0.6(5) | - 2.4(9) | + 3.1(6) | + 0.3(2) | + 1.2(4) | - 3.4(5) | + 1.1(6) |
| 4128.74(3) | - 8.4(2) | - 7.9(2) | -10.1(1) | + 0.2(1) | - 1.4(3) | + 3.3(1) | + 4.1(1) | + 5.5(2) | + 6.7(2) | - 4.3(1) |
| 4173.45(8) | - 2.1(9) | - 5.2(7) | - 1.3(9) | | - 0.8(9) | + 0.6(7) | + 2.3(5) | + 2.2(8) | - 1.6(7) | + 0.7(8) |
| 4178.86(8) | - 8.5(3) | - 7.4(5) | - 5.1(4) | - 5.0(3) | - 5.2(8) | + 0.1(5) | - 3.9(3) | - 0.4(5) | - 3.6(7) | - 3.0(5) |
| 4233.17(11) | - 3.3(6) | - 5.8(x) | - 2.3(9) | - 2.0(9) | - 1.1(x) | + 0.6(9) | + 2.6(8) | + 1.1(9) | + 0.1(x) | - 1.4(7) |
| 4258.16(3) | - 7.7(4) | - 2.4(7) | - 4.2(8) | - 2.5(3) | - 2.3(7) | + 3.2(7) | + 5.4(4) | + 4.6(3) | - 1.3(6) | + 0.8(6) |
| 4273.32(3) | - 1.2(3) | - 7.4(6) | - 3.4(5) | - 1.0(6) | - 4.4(8) | + 1.5(0) | + 1.5(3) | + 4.9(3) | - 1.8(6) | - 0.4(4) |
| 4296.57(6) | - 0.6(5n) | - 6.7(4) | - 4.5(3) | - 3.6(3) | - 4.3(5n) | - 0.1(6) | + 0.1(3n) | - 6.4(2n) | + 0.1(9) | + 2.1(7) |
| 4303.17(8) | - 1.2(4) | - 2.7(6) | | - 2.0(4) | - 3.6(7) | + 0.3(5) | - 0.3(3) | - 2.7(5) | - 2.3(9) | - 1.3(6) |
| 4314.29(4) | -12.0(1n) | + 3.1(1) | - 1.0(1n) | - 9.2(1) | - 5.5(1) | + 0.4(2) | + 1.7(0) | - 0.2(2) | + 0.3(3) | - 1.1(3) |
| 4351.76(9) | - 3.2(3) | - 8.2(7) | - 5.0(6) | - 2.1(3) | - 3.9(8) | - 1.0(5) | - 2.3(3) | - 1.0(5) | - 0.6(9) | + 1.3(8) |
| 4357.57(4) | - 9.6(1) | - 9.4(5) | - 7.3(5) | - 0.8(3) | - 4.9(3) | - 4.3(1) | + 1.4(0) | + 4.2(2) | - 3.2(3) | - 1.4(4) |
| 4385.38(7) | - 2.7(3) | - 5.0(9) | - 5.1(8) | - 1.4(4) | - 3.5(9) | + 1.3(6) | + 0.3(4) | - 1.5(5) | + 0.1(8) | + 1.4(7) |

| 3.490 | 3.530 | 3.721 | 4.460 | 4.520 | 4.956 | 5.050 | 5.430 | Blends |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | | |
| | | | | | | | | (Pr II .764(15)) |
| - 0.4(1) | - 2.5(2) | + 0.8(2) | + 8.1(3) | + 3.6(5) | + 7.0(3) | + 9.1(3) | | |
| - 0.5(1) | - 2.3(2) | - 2.9(1) | + 1.5(2) | + 3.8(3) | + 3.6(1n) | + 5.2(1) | -10.1(3n) | Mn II .50(3) Pr II .440(60) (Nd II .570(15)) (Nd II .443(50) (Zr II .21(6) |
| - 5.4(0) | | -11.2(1) | + 3.0(2) | - 0.8(1n) | | - 2.2(2) | + 7.1(2) | Ce II .362(60) (F II .177(150)) |
| + 1 6(1) | - 1.4(2) | - 2.8(2) | + 2.7(2) | + 2.9(3) | +12.0(2?) | +18.1(2n) | | (La II .44(100)) |
| - 1.2(2) | | - 7.6(2) | - 9.0(2) | - 7.4(7) | -12.0(4n) | - 7.8(3) | - 7.4(6) | |
| + 8.7(0) | - 8.3(1) | | - 0.2(0) | + 1.2(1) | + 7.7(1) | + 3.1(1) | - 1.6(0) | |
| | | + 0.6(1) | | + 5.8(0) | | | | |
| | - 7.4(0) | | + 0.8(0) | | | | | |
| | | -10.7(1) | + 0.9(1) | - 0.1(1n) | + 2.0(1) | - 2.5(1) | + 0.1(1) | |
| - 9.1(0) | | + 4.2(1n) | | | | - 6.2(1) | - 7.4(1) | |
| | | -10.2(0) | + 5.7(1) | + 4.6(0) | +12.6(1) | + 5.7(2) | | |
| - 1.86 (18) | - 2.69 (16) | - 2.91 (32) | + 2.49 (28) | + 1.86 (25) | + 5.01 (30) | + 4.93 (32) | - 2.12 (16) | |
| | | | | | | | | |
| | | | | | | | | (Gd II .02(50)) |
| | | - 2.4(2) | + 1.8(3) | | + 7.8(4) | +10.2(4) | | Cr II .95(1) (Cr II .06(0)) |
| | | - 0.5(2) | + 2.7(2) | | + 5.6(3) | + 7.5(2) | | Fe I .174(100) (Cr II .16(1)) |
| | | + 1.0(1) | + 7.4(1) | | + 5.4(2) | +10.9(3) | | Nd II .886(100) (Nd II .096(10)) (Ho II .78(30)) |
| - 0.5(3) | | + 0.8(2) | + 3.6(4) | | + 8.4(4) | +11.0(5) | | Gd II .971(50) (Nd II .874(40)) |
| | + 0.6(3) | - 1.4(3) | + 1.3(2) | + 2.2(2n) | + 0.8(2) | + 5.0(1) | | (Ce II .914(125)) |
| | - 4.2(1n) | - 2.3(2) | + 0.7(2) | + 0.2(2) | + 7.4(1) | + 8.6(1) | | Gd II .981(500) (Tb II .30(15)) (Gd II .223(10)) |
| - 1.2(1) | | - 2.9(1n) | + 3.4(1) | | + 3.7(0) | +10.6(1) | | (Zr II .45(12)) (Nd II .785(30)) |
| - 1.0(3) | - 1.2(3) | - 6.0(3) | - 0.9(3n) | - 2.2(4) | + 1.7(3) | + 5.8(3) | | Gd II .597(90) (Zr II .68(25)) (Nd II .814(15)) |
| + 8.6(3) | +11.5(4) | - 9.3(0) | - 0.6(1) | + 2.4(1) | -16.8(1) | - 9.9(2) | -13.3(2n) | |
| + 0.3(3) | - 0.4(9) | - 1.5(3) | + 0.7(3) | + 0.2(6) | + 6.9(4) | + 8.8(4) | + 3.1(1) | (Fe I .510(70)) |
| + 3.1(1) | - 5.6(1) | - 5.2(1) | + 2.9(1) | + 1.6(2) | + 2.0(2) | + 4.4(1) | +14.2(1) | |
| 0.0(5) | + 0.6(8) | - 3.7(4) | + 1.4(3) | - 1.1(9) | + 3.4(9) | + 4.5(7) | + 3.2(4) | Ti II .549(40) Gd II .556(100) (Nd II .379(8)) |
| + 0.5(4) | - 2.6(5) | - 0.7(3) | + 1.6(2) | - 1.7(7) | + 4.2(4) | + 7.2(4) | -12.1(1) | (Tb II .97(15)) |
| - 0.4(9) | - 2.2(9) | - 3.3(9) | + 2.8(9) | + 1.4(9) | + 3.8(9) | + 2.8(7) | + 2.3(x) | Cr II .25(10) (Pr II .134(10)) |
| + 0.9(3) | - 0.3(5) | - 0.4(4) | + 4.5(4) | + 3.7(9) | + 3.6(3n) | + 5.6(3n) | - 1.4(6) | (Eu II .19(8)) (Zr II .05(12)) |
| - 1.2(3) | - 3.0(4) | - 2.6(4) | + 2.2(4) | + 4.0(7) | + 4.8(4) | + 9.4(3) | - 1.5(6) | |
| - 0.6(4) | + 2.5(4) | - 0.9(8) | + 4.8(5) | + 2.7(9) | | + 7.9(3) | +10.1(6n) | Gd II .30(400) |
| + 2.8(5) | + 3.3(9) | - 1.9(4) | + 3.3(3) | + 1.2(9n) | + 5.8(3) | + 6.3(1) | | |
| + 0.3(1) | + 1.4(3) | - 3.1(2) | | + 2.6(4) | + 6.2(3) | | + 7.5(1) | (Gd II .28(10)) (Nd II .369(8)) (Nd II .511(5)) |
| - 3.5(4) | + 0.2(6) | - 0.6(8) | + 4.8(8) | + 2.6(x) | + 7.1(7) | + 8.9(8) | + 7.1(5) | (Cr I .770(300)) (Pr II .849(50)) (Tb II .57(8)) |
| + 2.1(2) | - 6.1(2) | - 3.1(2) | - 0.1(1) | - 1.3(4) | + 4.7(2) | + 8.1(2) | - 5.8(1) | |
| + 2.3(5) | - 4.0(4) | - 3.4(9) | + 2.0(4) | - 0.5(8) | + 1.3(5) | + 6.1(4) | + 0.8(3) | (Nd II .663(150)) (Dy II .29(2)) (La II .20(40)) |

TABLE 4 -- Continued

| Laboratory λ | 0.500 | 0.691 | 0.822 | 0.981 | 1.323 | 1.460 | 1.510 | 1.642 | 2.363 | 2.580 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Fe II - Continued** | | | | | | | | | | |
| 4416.82(7) | - 6.0(1) | - 6.2(4) | - 6.0(4) | - 2.7(3) | - 4.6(5) | - 0.5(4) | - 6.3(2) | - 1.2(6) | - 3.1(x) | + 1.8(5) |
| 4451.54(4) | - 2.4(0) | - 8.8(3) | - 7.5(4) | + 3.8(1) | - 1.0(3) | - 0.3(3) | - 6.5(1n) | + 2.2(2) | - 4.4(3) | - 2.0(3) |
| 4455.26(3) | | - 7.8(1n) | - 3.8(1) | - 8.2(1n) | - 3.3(2) | + 0.3(2) | - 1.5(1) | - 7.4(1) | - 2.8(3) | - 4.0(2) |
| 4491.41(5) | - 5.9(1) | - 8.0(5) | - 6.8(3) | - 1.7(3) | - 2.3(5) | + 1.7(5) | - 0.9(1) | - 4.5(3) | - 3.7(6) | - 3.8(3) |
| 4508.28(8) | - 4.8(3) | - 7.2(9) | - 4.7(4) | - 0.2(3) | - 2.2(8) | + 1.4(6) | + 2.9(2) | - 1.7(5) | - 2.7(9) | - 3.7(5) |
| 4515.34(7) | +10.1(5) | - 7.0(6) | - 7.6(7) | + 8.5(5) | - 0.3(x) | + 8.7(9) | + 6.4(3) | + 5.2(3) | 0.0(8) | + 2.3(5) |
| 4520.24(7) | - 9.8(3) | - 8.1(7) | - 6.8(3) | + 2.1(3) | - 5.6(6) | - 1.1(5) | - 9.9(2) | - 2.7(3) | - 4.5(7) | - 1.3(3) |
| 4522.63(9) | + 1.6(4) | - 5.4(8) | - 4.1(6n) | - 0.5(3) | - 1.9(7) | + 0.1(4) | - 7.1(1) | + 2.2(6) | - 1.3(8) | + 1.2(4) |
| 4541.52(4) | + 1.4(1n) | - 8.2(5) | - 7.3(3) | | | - 4.2(4) | - 4.3(3) | - 1.4(4) | - 3.2(5) | - 4.6(3) |
| 4549.47(10) | + 4.9(9) | - 2.6(9) | - 1.9(xn) | | | 0.0(x) | - 2.4(5) | - 2.2(9) | - 4.2(x) | - 3.0(9) |
| 4555.90(8) | - 1.0(2) | - 4.7(5) | - 6.2(3) | | | - 0.7(5) | + 2.3(1) | + 2.3(4) | - 4.0(8) | + 0.6(4) |
| 4576.33(4) | +13.5(1) | - 4.4(5) | - 2.5(1) | | | - 3.1(2) | | + 3.0(3) | - 0.3(5) | - 5.0(3) |
| 4582.84(3) | + 4.9(2) | - 5.0(6) | -10.5(3) | | | - 3.4(3) | - 4.5(1) | + 0.7(4) | - 2.1(4) | - 5.4(2) |
| 4583.85(11) | + 5.7(5n) | - 5.2(9) | - 4.1(5) | | | - 1.0(5) | - 3.7(1) | + 3.6(5) | - 2.7(9) | + 2.1(4) |
| 4620.51(3) | | - 4.5(4) | - 5.5(3) | | | + 0.9(4) | | | - 4.6(7) | + 5.3(1) |
| 4629.33(7) | | - 6.9(8) | 0.0(5) | | | - 0.7(5) | | | - 1.5(6) | - 6.9(3) |
| 4635.33(5) | | - 5.1(7) | - 5.4(3) | | | - 1.5(4) | | | - 1.4(6) | - 5.0(2) |
| Mean<br>Number of measures | - 3.17<br>(32) | - 5.9<br>(39) | - 7.76<br>(38) | - 1.29<br>(22) | - 3.02<br>(30) | + 0.11<br>(36) | - 0.72<br>(28) | + 0.84<br>(34) | - 1.69<br>(39) | - 0.96<br>(35) |
| **Ni I** | | | | | | | | | | |
| 4401.55(1000) | + 8.7(2) | + 3.3(5) | + 4.6(3) | + 4.2(1) | +12.6(1) | + 6.1(1) | +12.2(1) | +10.2(0) | + 8.0(1n) | + 5.2(0) |
| Mean<br>Number of measures | + 8.7<br>(1) | + 3.3<br>(1) | + 4.6<br>(1) | + 4.2<br>(1) | +12.6<br>(1) | + 6.1<br>(1) | +12.2<br>(1) | +10.2<br>(1) | + 8.0<br>(1) | + 5.2<br>(1) |
| **Sr II** | | | | | | | | | | |
| 4215.52(400) | + 3.1(5n) | + 7.2(4n) | + 8.3(8) | + 8.5(5) | + 5.2(7) | + 8.4(4) | +11.6(3) | +11.8(3) | + 3.8(3) | + 2.0(4) |
| Mean<br>Number of measures | + 3.1<br>(1) | + 7.2<br>(1) | + 8.3<br>(1) | + 8.5<br>(1) | + 5.2<br>(1) | + 8.4<br>(1) | +11.6<br>(1) | +11.8<br>(1) | + 3.8<br>(1) | + 2.0<br>(1) |
| **Ce II** | | | | | | | | | | |
| 3942.75(150) | - 7.2(1) | - 8.8(2) | - 2.3(1) | | + 0.2(1) | + 5.4(0) | | + 8.9(0) | - 6.7(0) | - 6.5(0) |
| 3952.57(125) | - 6.4(3) | - 4.0(4) | - 1.3(2) | | + 6.0(2) | + 7.6(3) | | +13.2(0) | - 4.4(1) | - 5.2(1) |
| 3980.90(100) | - 5.0(2) | - 2.6(3) | - 1.4(1) | | + 1.3(2) | | | - 6.6(1n) | -10.9(0) | - 1.9(1) |
| 4133.80(500) | | - 6.4(2) | -19.5(1n) | + 0.2(0) | + 3.1(1) | + 0.9(1) | | -15.5(1) | -12.8(3) | |
| 4186.60(600) | -10.0(2) | + 1.4(1) | + 0.9(1n) | + 8.1(1) | + 8.3(2) | +10.2(1) | | - 4.6(1n) | - 6.4(1) | -10.2(0) |
| 4289.94(300) | +15.5(9) | +15.7(x) | +19.6(9) | +20.6(5) | +18.4(4n) | +23.3(4) | +26.5(1) | | + 6.4(3n) | + 5.2(2) |
| 4391.66(250) | - 1.3(1n) | - 2.3(4) | - 1.2(3) | + 0.9(1) | + 2.5(3) | + 8.8(3) | + 8.4(1) | +10.6(1) | + 4.0(1) | |
| 4449.34(200) | - 2.4(1n) | - 7.0(3) | - 1.6(2) | | | | +15.0(1) | | | +11.7(1) |
| Mean<br>Number of measures | - 2.4<br>(7) | - 1.75<br>(8) | - 0.08<br>(8) | + 7.45<br>(4) | + 5.68<br>(7) | + 9.36<br>(6) | +16.63<br>(3) | + 1.0<br>(6) | - 4.4<br>(7) | - 2.85<br>(6) |

| 3.490 | 3.530 | 3.721 | 4.460 | 4.520 | 4.956 | 5.050 | 5.430 | Blends |
|---|---|---|---|---|---|---|---|---|
| - 2.1(4) | - 0.9(5) | - 3.3(x) | + 0.1(3) | + 1.3(5) | + 4.8(5) | + 6.0(3) | + 7.0(3) | (Nd II .884(15)) |
| + 1.7(2) | - 6.4(2) | - 5.6(3n) | + 0.1(3n) | + 1.8(4) | + 3.3(3n) | + 5.8(3) | | Nd II .566(400) (Mn I .586(125)) (Eu II .63(2)) |
| - 0.9(1) | - 6.2(1n) | - 5.3(2n) | + 1.6(2) | + 0.2(3n) | + 0.7(2) | + 3.8(2) | + 6.5(2) | (Ti I .326(150)) (Dy II .49(4)) |
| - 0.5(3) | - 0.3(3) | - 2.5(3) | - 1.9(2) | + 2.1(4n) | + 1.2(3) | + 6.3(3) | - 3.7(1) | (Nd II .644(3)) |
| - 1.1(4) | - 5.4(5) | - 3.0(6) | - 1.0(3) | - 2.6(8) | + 0.4(5n) | + 3.3(5) | - 2.4(3) | |
| + 4.6(5) | + 4.9(4) | + 0.9(5n) | - 0.5(3n) | + 1.1(9) | + 4.0(5) | + 4.4(7) | + 5.4(6) | |
| 0.0(4) | - 0.6(6) | - 5.6(7) | + 0.4(3) | + 1.7(6) | - 0.8(3) | - 3.1(3) | - 8.3(1) | (Gd II .070(150)) (Tb II .09(4)) |
| - 2.8(5) | - 2.4(8) | - 2.1(7) | + 2.4(4) | + 1.7(9) | + 1.3(9n) | + 8.4(4) | + 7.0(5) | Eu II .57(2000) |
| + 0.7(5) | - 4.0(4) | - 4.0(4) | - 0.4(4) | + 0.8(7) | + 3.8(9) | + 4.6(8) | + 6.0(3) | |
| - 0.5(9) | - 3.7(9) | - 6.0(x) | + 2.5(9) | + 0.5(x) | + 0.5(x) | + 2.1(x) | + 7.6(9) | (Fe II .214(4)) (Eu II .52(6)) (S II .547(80)) |
| + 4.1(3) | - 1.2(4) | - 5.5(4) | + 2.4(3) | + 0.3(9) | + 5.9(3) | + 1.6(2) | + 6.6(2n) | |
| + 1.5(3) | - 0.6(2) | - 1.5(6) | + 2.8(3) | - 0.5(4) | + 5.3(5) | + 5.9(3) | + 3.5(2) | Eu II .35(12) (Pr II .320(20)) |
| - 8.2(2) | - 4.0(3) | - 3.6(3n) | + 0.3(2) | -13.6(4n) | + 1.8(2) | + 9.0(2n) | - 5.7(3) | |
| + 2.0(6) | + 0.5(7) | - 2.2(8) | - 0.1(7) | + 1.5(9) | + 3.8(9) | + 7.5(9) | +12.0(3) | |
| + 4.2(1) | - 3.5(1) | - 4.3(3) | + 0.5(3) | 0.0(4) | + 2.7(4) | + 5.1(4) | | (Gd II .45(15)) |
| + 0.9(3) | - 5.0(3) | - 1.4(3) | + 3.6(4) | - 1.2(4) | + 4.0(3) | + 7.4(3) | | (Ti (II?) .337(15)) |
| + 2.1(4) | - 2.3(3) | - 4.2(4) | - 3.6(3) | - 3.6(3) | + 2.5(3) | + 5.1(3) | | |
| + 0.54 (34) | - 1.49 (34) | - 2.89 (39) | + 1.57 (38) | + 0.28 (34) | + 3.24 (38) | + 5.87 (38) | + 2.14 (26) | |
| | | -12.8(1) | - 8.2(2) | - 7.9(4) | -11.5(5) | - 2.0(5) | + 8.8(5) | (Fe I .300(60)) (Tb II .54(10)) |
| (0) | (0) | -12.8 (1) | - 8.2 (1) | - 7.9 (1) | -11.5 (1) | - 2.0 (1) | + 8.8 (1) | |
| + 4.8(2) | + 5.0(3) | + 9.9(2) | + 1.8(2) | + 1.5(3) | + 5.3(3) | + 3.1(4) | + 2.3(3) | (Cr II .77(2)) (Zr II .76(1)) |
| + 4.8 (1) | + 5.0 (1) | + 9.9 (1) | + 1.8 (1) | + 1.5 (1) | + 5.3 (1) | + 3.1 (1) | + 2.3 (1) | |
| | +10.6(0) | | | - 1.6(1) | + 8.0(1) | | | (Nd II .631(6)) |
| | - 4.5(1n) | -15.3(1) | - 7.4(1) | - 6.4(1) | + 1.3(1) | - 5.0(2n) | | Fe I .606(80) (Nd II .870(25)) |
| | -14.2(0) | | - 9.3(1n) | - 1.0(0) | | | | |
| - 5.5(0) | -12.0(1) | -18.3(1) | -14.2(1) | - 7.4(3) | - 9.5(2) | - 7.9(0) | | (Pr II .618(15)) |
| + 5.4(0) | + 2.6(0n) | | - 4.6(1) | - 3.6(3) | - 2.4(1) | + 4.9(2) | - 1.8(1n) | (Zr II .70(12)) |
| | + 9.4(1n) | +12.2(1) | + 4.5(4n) | + 2.7(7n) | + 5.7(5) | + 5.3(5) | +10.6(9) | Ti II .227(60) Gd II .884(80) |
| | - 2.8(1) | + 1.2(1) | - 4.0(0n) | - 1.1(2n) | + 1.0(1) | + 3.1(1n) | - 1.4(1) | Gd II .445(15) (Eu II .37(10)) (S II .84(30)) |
| | + 7.6(2) | | -14.6(1) | -18.0(1) | -21.1(1) | -15.4(2) | -10.7(2) | Ti II .148(150) (Dy II .16(2)) |
| + 0.05 (2) | - 0.41 (8) | - 5.05 (4) | - 7.08 (7) | - 4.55 (8) | - 2.43 (7) | - 2.5 (6) | - 0.82 (4) | |

TABLE 4 -- Continued

| Laboratory λ | 0.500 | 0.691 | 0.822 | 0.981 | 1.323 | 1.460 | 1.510 | 1.642 | 2.363 | 2.580 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Pr II** | | | | | | | | | | |
| 4033.86(75) | - 7.7(3) | - 6.5(2) | - 6.3(2) | + 0.4(0) | - 4.4(1n) | - 3.9(1n) | - 3.4(1) | | -21.8(0) | -12.4(0) |
| 4408.84(200) | | - 7.5(1) | - 6.8(2) | + 0.5(1) | - 0.5(2) | + 0.9(0) | | | -11.4(1) | |
| 4510.16(100) | | - 6.5(3) | - 7.6(3) | + 1.7(0) | - 0.5(1) | + 5.5(1) | | + 2.3(1) | +10.6(1n) | - 2.5(0) |
| Mean<br>Number of measures | - 7.7<br>(1) | - 6.83<br>(3) | - 6.9<br>(3) | + 0.87<br>(3) | - 1.8<br>(3) | + 0.83<br>(3) | - 3.4<br>(1) | + 2.3<br>(1) | - 7.53<br>(3) | - 7.45<br>(2) |
| **Nd II** | | | | | | | | | | |
| 3901.85(50) | + 1.3(0) | - 8.8(2) | -12.5(2) | | - 8.8(2) | | | - 7.0(0n) | -24.6(1n) | |
| 4390.66(20) | -12.6(0) | -11.4(4) | -14.8(2) | - 9.4(1) | -13.0(1) | - 9.4(1) | | - 4.0(1) | | |
| Mean<br>Number of measures | - 5.65<br>(2) | -10.1<br>(2) | -13.65<br>(2) | - 9.4<br>(1) | -10.9<br>(2) | - 9.4<br>(1) | (0) | - 5.5<br>(2) | -24.6<br>(1) | (0) |
| **Sm II** | | | | | | | | | | |
| 4362.04(300) | + 7.4(1) | +10.6(2n) | -22.3(1) | +15.9(0) | + 2.2(1) | - 0.9(0) | | + 4.7(0) | - 9.3(1) | |
| 4424.34(600) | + 0.8(1) | + 3.7(2) | +11.9(1) | -12.4(0n) | + 6.2(1) | + 6.8(0) | + 2.9(0) | | + 1.7(0) | |
| 4434.32(400) | - 6.4(3) | + 1.3(4n) | + 2.1(4) | - 6.9(1n) | + 1.5(2) | - 7.6(1n) | - 6.6(1n) | + 8.9(0) | -12.0(1) | |
| Mean<br>Number of measures | + 0.6<br>(3) | + 5.2<br>(3) | - 2.77<br>(3) | - 1.13<br>(3) | + 3.3<br>(3) | - 0.57<br>(3) | - 1.85<br>(2) | + 6.8<br>(2) | - 6.53<br>(3) | (0) |
| **Eu II** | | | | | | | | | | |
| 3724.94(4000) | | + 1.3(2) | | | + 6.8(1) | | | | | |
| 3765.93(150) | | +21.2(0) | | | | | | | | |
| 3819.67(6000) | | + 4.5(7) | + 4.9(5) | | + 4.9(3) | | | +10.9(1) | - 9.7(1) | |
| 3907.10(3000) | + 5.3(9) | + 7.4(9) | +10.5(4) | | +12.4(3) | +15.0(2) | | - 4.2(1n) | + 2.8(1n) | + 1.8(0n) |
| 3917.29(60) | + 5.1(1n) | + 6.1(1n) | +15.6(1) | | + 1.9(1) | +12.8(1) | | +14.3(0) | +11.7(1n) | |
| 3971.96(4000) | + 6.9(3) | + 7.6(5) | +14.3(1) | | +10.6(2) | +10.6(1) | | | | |
| 4011.69(100) | + 4.8(1) | +10.5(0) | +15.9(0) | | +21.9(0) | | | | | |
| 4129.70(5000) | +10.1(9) | + 8.9(9) | + 9.9(6) | +16.0(6) | +14.5(4) | +15.8(3) | +20.6(1) | +20.3(1) | - 5.5(0) | + 4.0(0) |
| 4141.02(25) | + 6.4(1) | + 2.3(1) | + 7.2(1) | +10.4(1) | + 5.4(1) | +14.3(0) | | | + 1.4(0) | |
| 4205.05(6000) | + 3.4(x) | + 2.7(9n) | + 4.0(5) | +10.6(5n) | +10.0(5n) | | +24.4(2n) | +23.5(3n) | -14.4(1) | - 7.7(1) |
| 4435.56(3000) | + 7.4(4) | + 6.2(5) | + 6.6(3) | +13.3(1) | + 9.9(2) | | | | | |
| Mean<br>Number of measures | + 6.18<br>(8) | + 7.16<br>(11) | + 9.88<br>(9) | +12.58<br>(4) | + 9.83<br>(10) | +13.7<br>(5) | +22.5<br>(2) | +12.96<br>(5) | - 2.28<br>(6) | - 0.63<br>(3) |

| 3.490 | 3.530 | 3.721 | 4.460 | 4.520 | 4.956 | 5.050 | 5.430 | Blends |
|---|---|---|---|---|---|---|---|---|
| | -20.7(0) | -20.0(1) | -23.3(1) | -24.9(0) | -22.5(2) | -18.8(3) | | Dy II .666(10) (P II .68(15)) |
| | | | - 1.4(1) | - 6.9(2) | - 3.0(1) | + 4.8(1) | | |
| | -11.2(0) | -21.2(1) | -14.2(1n) | - 7.7(4) | -17.8(3) | - 5.2(2n) | - 7.6(4) | Mn II .210(3) |
| (0) | -15.9 (2) | -20.6 (2) | -13.0 (3) | -13.17 (3) | -14.43 (3) | - 6.4 (3) | - 7.6 (1) | |
| | | | -29.9(1n) | | -25.3(2) | -20.5(4) | | (Eu II .63(3) (Tb II .60(6)) |
| | -15.6(1) | -14.9(0) | -27.2(1) | -27.2(0n) | -22.5(2) | -21.0(3) | -11.8(2) | Mg II .585(10) (Eu II .36(3)) |
| (0) | -15.6 (1) | -14.9 (1) | -28.6 (2) | -27.2 (1) | -23.9 (2) | -20.75 (2) | -11.8 (1) | |
| | | + 2.5(1) | - 4.4(1) | -12.4(1) | - 7.8(2n) | - 6.7(2) | + 6.2(3) | Ni II .10(1) Ce II .661(18) |
| | | | - 9.8(1n) | -15.6(2n) | -10.3(3) | - 3.9(3) | + 1.6(3) | Gd II .102(40) (Pr II .595(25)) |
| | | -16.2(2) | -12.5(3) | -11.8(6) | - 8.9(6) | -11.9(5) | - 6.2(8) | (Tb II .48(10)) |
| (0) | (0) | - 6.85 (2) | - 8.9 (3) | -13.27 (3) | - 9.0 (3) | - 7.5 (3) | + 0.53 (3) | |
| | | -19.1(1) | -15.1(1) | | -11.4(2) | - 5.7(2) | | (Mn II .81(1)) (Nd II .877(30)) (La II .05(20)) (Sm II .902(200)) |
| | | | + 3.3(0) | | | +13.0(0) | | |
| | | +13.3(0) | - 9.3(3) | | - 8.1(7) | - 4.6(9) | | |
| + 6.8(1n) | | - 3.1(0n) | -12.2(2n) | | - 7.8(5) | - 4.9(8) | | |
| - 1.5(0) | | | - 4.4(1) | | + 1.9(1) | + 2.8(1) | | Sm II .442(200) (Pr II .229(20)) |
| + 9.2(0) | | -12.3(0) | - 5.1(0) | | -10.6(5) | - 5.1(6) | | Gd II .754(300) (Gd II .166(30)) (Ce II .684(10)) (Tb II .05(20)) (Pr II .693(25)) (Pr II .164(100)) |
| | | | - 8.4(2) | - 8.8(1) | - 2.6(1) | - 4.1(2) | | |
| | | - 5.8(1n) | + 0.6(2) | - 3.5(4) | + 0.7(7) | + 0.7(8) | + 3.5(1) | |
| + 1.4(0) | + 1.3(0) | - 7.7(0) | | + 8.2(1n) | - 1.7(0) | - 5.9(1) | + 5.1(0) | Gd II .017(25) |
| | | -22.5(1n) | -12.0(1) | -11.9(6) | -10.0(7) | - 3.9(9) | - 2.8(9) | Gd II .857(300) (V II .080(250)) (Cr II .83(pr)) |
| | | | - 9.6(2n) | -10.0(6) | - 9.4(9) | - 7.6(9) | - 1.2(9) | (Dy II .78(1)) |
| + 3.98 (4) | + 1.3 (1) | - 8.17 (7) | - 7.22 (10) | - 5.2 (5) | - 5.90 (10) | - 2.30 (11) | + 1.15 (4) | |

TABLE 4 -- Continued

| Laboratory λ | 0.500 | 0.691 | 0.822 | 0.981 | 1.323 | 1.460 | 1.510 | 1.642 | 2.363 | 2.580 |
|---|---|---|---|---|---|---|---|---|---|---|
| Gd II | | | | | | | | | | |
| 3902.40(1000) | + 0.2(3) | - 1.9(2) | - 1.1(1) | | + 6.5(1) | + 8.2(1) | | + 7.8(0) | | |
| 3923.25(300) | + 8.9(7) | +10.2(5) | + 9.0(3) | | +13.6(2) | | | +14.4(0) | +13.3(0) | |
| 3934.82(300) | + 1.8(2) | + 3.5(3) | + 2.7(1) | | + 7.2(2) | + 7.3(1) | | +15.2(1) | +15.8(0n) | + 8.9(1) |
| 3957.67(1000) | +14.5(5) | +12.7(5) | +13.6(2) | | +18.6(3) | - 6.5(0) | | | +15.2(1n) | |
| 3959.52(500) | + 0.3(3n) | - 1.7(3n) | 0.0(2) | | + 0.6(1) | + 2.3(0) | | -13.6(0) | + 6.9(1) | -12.9(0) |
| 4008.91(400) | + 3.2(0) | -19.5(2) | -15.9(1) | -10.2(0) | - 9.6(2) | - 6.4(1) | | + 1.3(1) | | |
| 4037.33(1500) | + 2.2(4) | + 9.5(3) | + 2.0(2) | +12.1(1) | +10.0(1) | - 4.1(1) | - 6.6(0) | - 4.9(1) | | -10.5(1) |
| 4047.81(100) | + 7.8(1) | +10.9(2) | + 4.5(1) | + 7.2(1) | + 1.9(1) | +10.2(1) | | +12.4(0) | | - 1.6(0) |
| 4053.29(1000) | + 6.1(3) | + 6.4(4) | | + 8.5(3) | + 6.3(5) | +10.0(3) | +11.3(1n) | | + 0.8(1) | |
| 4073.20(400) | + 3.4(3) | + 1.1(3) | + 5.5(2) | +12.2(1) | + 3.5(2) | + 5.7(1) | | + 8.3(1) | + 9.1(1) | |
| 4078.44(1200) | + 9.2(2) | +10.0(3) | + 7.0(1) | +10.6(1n) | + 5.2(1) | +12.6(1) | | -11.5(1) | - 8.2(1) | - 6.0(1) |
| 4111.44(500) | - 9.9(1) | - 3.6(2) | - 3.1(1) | + 1.5(0) | + 3.1(3) | +10.3(0) | | | | |
| 4130.37(3000) | +10.6(1) | + 3.3(3) | + 1.5(1) | + 9.1(0) | + 7.6(1) | + 7.9(1) | | | - 8.4(1) | |
| 4132.28(2000) | + 4.6(1) | + 1.4(2) | | | + 7.1(4) | - 8.5(0) | - 3.8(1) | | -11.0(1) | + 2.8(2n) |
| 4184.25(2000) | + 2.3(5) | + 2.6(4) | + 2.9(2) | + 5.3(3) | + 1.9(3) | + 7.2(3) | + 7.0(1) | + 2.5(2n) | - 3.1(1) | + 2.0(2) |
| 4191.07(800) | +10.0(2) | + 5.7(2) | +15.9(2) | + 9.5(1) | +10.5(2) | | | +23.0(1) | | |
| 4202.52(80) | - 6.5(2) | - 5.8(3) | - 7.1(4) | - 3.2(3) | - 3.4(3) | + 3.4(2) | + 2.5(1) | | | |
| 4212.00(800) | - 4.2(3) | - 4.4(2n) | - 2.7(3) | + 2.1(2n) | + 3.1(1) | + 0.1(1n) | - 0.9(0) | | - 7.3(1) | + 2.3(1) |
| 4392.07(100) | +15.9(0) | + 5.3(0) | + 7.1(1) | | + 5.1(0) | +15.8(0) | | | | |
| 4408.25(400) | + 3.5(1) | + 0.8(4) | + 1.1(4) | +10.7(1) | + 3.3(3) | +11.7(1) | | +11.2(1) | | |
| 4471.29(200) | | - 7.4(2) | - 7.1(1) | | + 0.5(2) | - 9.4(3) | - 3.5(1) | | -10.1(1n) | - 8.5(1n) |
| 4483.33(300) | +12.5(3) | + 9.0(4) | + 9.2(2) | +11.8(1) | +12.2(3) | +13.6(1) | | +11.4(0n) | - 5.0(1) | + 5.6(0) |
| 4558.08(250) | + 5.1(0) | + 3.5(3) | + 3.0(1) | | | | | | | |
| Mean<br>Number of measures | + 4.61<br>(22) | + 2.24<br>(23) | + 2.28<br>(21) | + 6.23<br>(14) | + 5.22<br>(22) | + 4.57<br>(20) | + 0.86<br>(7) | + 5.96<br>(13) | + 0.62<br>(13) | - 1.79<br>(10) |
| Dy II | | | | | | | | | | |
| 3898.54(500) | - 5.1(5) | - 2.7(5n) | - 2.5(3) | | + 1.4(4) | | | + 6.7(1) | + 1.2(1) | +10.9(1) |
| 3944.69(600) | - 0.7(5) | + 2.1(4) | + 5.1(3) | | + 6.8(3) | +14.4(1) | | | | |
| 3978.57(200) | + 2.1(5) | + 0.5(6) | + 2.9(3) | | + 5.8(3) | +10.8(2) | | + 8.9(1) | - 0.9(0) | + 1.3(1n) |
| 4000.45(800) | + 2.3(3) | - 0.3(2) | + 4.7(1) | | + 6.8(2) | + 6.1(1) | | +15.4(0) | | |
| 4027.79(30) | + 5.6(2) | + 7.7(3) | + 6.8(2) | + 7.9(1) | + 8.8(1) | +11.9(1) | | - 7.5(0) | | -11.5(1) |
| 4050.58(100) | - 4.1(3) | - 2.9(3) | - 2.6(3) | + 0.9(1) | + 1.5(2) | + 3.2(2) | | - 0.5(1) | | |
| 4143.10(150) | - 1.3(3) | + 3.2(3) | + 3.3(3) | + 9.3(2) | +10.4(2) | +15.4(2) | +16.0(1) | | + 2.9(1) | - 3.3(0) |
| 4409.38(200) | - 1.4(1) | + 5.2(5) | + 2.3(3) | + 1.4(1) | + 4.9(3) | +11.0(2) | +10.6(1) | + 9.3(1) | + 8.4(2) | + 2.6(1) |
| Mean<br>Number of measures | - 0.32<br>(8) | + 1.6<br>(8) | + 2.5<br>(8) | + 4.88<br>(4) | + 5.8<br>(8) | +10.4<br>(7) | +13.3<br>(2) | + 5.38<br>(6) | + 2.9<br>(4) | 0<br>(5) |
| Ho II | | | | | | | | | | |
| 4045.43(200) | -16.2(1) | -14.1(2) | -16.0(2) | - 0.7(0) | | - 5.6(0) | | | -17.7(0) | |
| Mean<br>Number of measures | -16.2<br>(1) | -14.1<br>(1) | -16.0<br>(1) | - 0.7<br>(1) | (0) | - 5.6<br>(1) | (0) | (0) | -17.7<br>(1) | (0) |

| 3.490 | 3.530 | 3.721 | 4.460 | 4.520 | 4.956 | 5.050 | 5.430 | Blends |
|---|---|---|---|---|---|---|---|---|
| | | | - 2.8(1n) | | +10.9(2) | +23.3(1) | | Pr II .470(25) (Dy II .39(2)) (Tb II .35(10)) |
| | + 6.9(0) | | -12.0(3) | - 5.9(3) | - 5.4(4n) | + 0.2(7) | | Gd II .329(80) Ce II .109(125) S II .483(200) Dy II .394(30) (Tb II .33(6)) (Ho II .37(5)) (Dy II .300(3)) |
| + 8.5(0) | - 6.4(1n) | -14.8(1) | - 7.4(2) | -10.7(1) | - 8.0(2) | - 4.3(3) | | Zr II .80(20) Nd II .823(50) Cr II .18(pr) |
| | + 8.2(0) | | - 5.6(1) | + 1.4(2) | + 3.9(2) | + 5.2(4) | | Dy II .802(40) |
| | | -13.9(1) | -10.4(1n) | -15.9(2) | - 9.3(2n) | - 6.9(3n) | | Gd II .436(300) Sm II .527(100) Dy II .35(3) |
| | | | -11.4(1n) | -14.0(1n) | - 2.1(2n) | - 7.7(2) | | Pr II .714(75) Eu II .87(6) |
| | | | -11.2(2) | - 9.9(4) | - 4.4(3) | - 1.6(4) | + 1.0(2) | (Eu II .149(5)) |
| - 4.1(0) | -11.5(1) | + 2.4(0n) | - 8.5(0) | -10.7(1) | -10.2(1) | + 0.3(1n) | + 2.4(1) | |
| + 7.2(1) | +11.4(1) | + 2.7(1) | - 3.5(3) | - 9.8(3) | + 2.7(3) | + 0.1(4) | + 4.7(1) | Cr II .45(1) |
| - 0.2(0) | | | | -12.1(4) | - 7.6(6) | - 4.2(4) | - 3.5(5) | Dy II .110(150) |
| - 7.2(1) | - 3.1(1) | - 5.9(2) | - 2.4(1) | - 6.4(4) | - 2.4(4) | - 4.8(3) | + 1.4(4) | Ce II .321(60) (Fe I .358(80)) (Ti I .474(125)) |
| | | | | | + 4.2(1) | + 6.0(0) | -12.8(1n) | Ce II .394(60) Dy II .346(125) |
| -10.8(0) | | - 7.8(0) | - 8.6(1) | - 8.5(2) | - 2.0(3) | - 5.7(1) | - 1.7(1) | |
| + 5.2(3) | - 0.1(3) | | - 3.3(0) | - 8.6(2) | - 3.0(1) | - 6.7(1) | | |
| - 0.5(1) | - 2.1(2) | | - 1.2(3) | - 2.6(4) | 0.0(4) | - 1.3(7) | + 4.7(5) | Lu II .26(120) (Pr II .242(8)) (Ti II .329(20)) |
| | | +14.5(0) | -12.5(1) | -13.1(3n) | - 4.6(2) | - 2.6(3n) | + 3.6(3) | (Gd II .355(10)) (A I .028(1200)) (Cr I .271(70)) |
| | | -17.2(0) | + 0.8(0) | | + 3.8(1) | -17.1(3) | -13.2(3) | (V II .350(150)) (Al II .4(8)) |
| | | -16.7(1) | - 9.3(2) | -10.8(5) | - 8.0(6) | - 5.9(5) | - 6.4(4) | |
| | | | | | - 9.2(0) | | | (Ne II .94(150)) |
| | | +21.4(1) | +11.6(0) | | + 2.2(1) | + 6.2(0) | | Fe I .419(125) |
| | - 4.6(2n) | -12.7(2) | - 4.6(1n) | - 7.3(2n) | - 0.3(1) | | - 1.1(1n) | Ce II .240(200) (Ti I .240(100)) |
| + 8.6(0n) | - 9.1(1) | - 8.7(1) | - 6.3(3) | - 4.5(4) | - 1.9(5) | - 1.6(6) | + 9.1(3) | (S II .424(100)) |
| | | | | | + 3.0(2) | + 7.5(0) | -12.2(0n) | (P II .03(100)) |
| + 0.74 (9) | - 1.04 (10) | - 4.7 (12) | - 5.72 (19) | - 8.79 (17) | - 2.07 (23) | - 1.03 (21) | - 1.71 (14) | |
| | | + 1.9(1) | - 9.3(1) | | - 9.7(3) | - 9.2(7) | | Cr II .49(1) (Gd II .402(10)) |
| | - 8.5(0) | | -13.4(1) | -14.3(1n) | - 8.6(3) | - 6.5(4) | | |
| - 2.6(0) | + 8.1(1) | -11.8(0) | -11.6(2) | -13.4(3) | - 9.6(3) | - 8.2(5) | | Ce II .650(125) |
| | | | -14.3(2) | -10.0(3) | - 8.2(3) | - 6.0(6) | | (Pr II .478(15)) (Nd II .493(30)) (Nd II .562(20)) |
| | -10.5(0) | | - 9.2(2) | - 9.4(3) | - 4.0(4) | - 3.6(3) | | |
| -12.8(0) | + 6.4(0) | | -13.0(1) | -10.1(3) | -10.2(3) | - 8.9(5) | - 0.6(5) | (Eu II .43(4)) |
| | | -11.2(1) | - 5.0(1) | - 6.3(3) | -13.1(2) | - 6.0(3n) | - 5.3(2) | Pr II .136(50) (Fe II .07(pr)) |
| + 2.9(1) | +11.6(1) | +13.0(2) | +22.4(2n) | | | | - 7.3(1) | Ti II .519(10) (Tb II .51(20)) |
| - 4.17 (3) | + 1.42 (5) | - 2.02 (4) | - 6.68 (8) | -10.58 (6) | - 9.06 (7) | - 6.91 (7) | - 4.4 (3) | |
| | | - 7.0(0) | - 3.9(0) | - 4.6(0) | - 2.2(1) | - 0.3(3) | + 9.0(1) | Gd II .148(100) |
| (0) | (0) | - 7.0 (1) | - 3.9 (1) | - 4.6 (1) | - 2.2 (1) | - 0.3 (1) | + 9.0 (1) | |

TABLE 5

OBSERVATIONS OF $\alpha^2$ CANUM VENATICORUM

| Plate No. | Date | U.T. | Phase in Days | Dispersion at λ 3933 | Used in Table |
|---|---|---|---|---|---|
| | | | | A/mm | |
| MtW 1667..... | 1938 May 13 | $6^h27^m$ | 0.822 | 3 | 3 |
| MtW 1669..... | 1938 May 14 | 4 40 | 1.642 | 3 | 3 |
| MtW 1992..... | 1939 Apr. 27 | 4 04 | 5.050 | 3 | 3 |
| MtW 1995..... | 1939 Apr. 28 | 4 26 | 0.691 | 3 | 3 |
| MtW 2229..... | 1940 Jan. 19 | 11 29 | 4.460 | 3 | 3 |
| CQ 377..... | 1940 May 12 | 7 22 | 2.93 | 40 | 2 |
| CQ 378..... | 1940 May 12 | 7 32 | 2.93 | 40 | 2 |
| CQ 385..... | 1940 May 13 | 7 22 | 3.94 | 40 | 2 |
| CQ 386..... | 1940 May 13 | 7 44 | 3.94 | 40 | 2 |
| CQ 387..... | 1940 May 14 | 7 45 | 4.93 | 40 | 2 |
| CQ 388..... | 1940 May 15 | 7 22 | 0.47 | 40 | 2 |
| CQ 389..... | 1940 May 15 | 7 40 | 0.47 | 40 | 2 |
| CQ 392..... | 1940 May 16 | 7 17 | 1.46 | 40 | 2 |
| CQ 393..... | 1940 May 16 | 7 45 | 1.46 | 40 | 2 |
| CQ 479..... | 1940 Aug. 19 | 2 09 | 3.77 | 40 | 1 |
| Cd 50..... | 1941 Jan. 21 | 10 37 | 0.500 | 2 | 3 |
| Cd 56..... | 1941 Jan. 22 | 9 38 | 1.460 | 2 | 3 |
| Cd 57..... | 1941 Jan. 22 | 10 46 | 1.510 | 2 | 3 |
| Cd 63..... | 1941 Jan. 23 | 12 26 | 2.580 | 2 | 3 |
| Cd 76..... | 1941 Jan. 24 | 10 16 | 3.490 | 2 | 3 |
| Cd 77..... | 1941 Jan. 24 | 11 23 | 3.530 | 2 | 3 |
| Cd 81..... | 1941 Jan. 25 | 11 01 | 4.520 | 2 | 3 |
| Cd 86..... | 1941 Jan. 26 | 8 53 | 5.430 | 2 | 3 |
| Cd 90..... | 1941 Jan. 27 | 9 15 | 0.981 | 2 | 3 |
| MtW 2540..... | 1941 Apr. 22 | 4 00 | 3.721 | 3 | 3 |
| MtW 2543..... | 1941 May 6 | 4 23 | 1.323 | 3 | 3 |
| MtW 2544..... | 1941 May 7 | 5 18 | 2.363 | 3 | 3 |
| MtW 2580..... | 1941 June 6 | 3 52 | 4.956 | 3 | 3 |

TABLE 6

CD 81—COMPARISON BETWEEN DIRECT AND REVERSE MEASUREMENTS

| Intensity | No. of Lines | Average Value of $\lambda_{direct}-\lambda_{reverse}$ | Average Absolute Value of $\lambda_{direct}-\lambda_{reverse}$ | Intensity | No. of Lines | Average Value of $\lambda_{direct}-\lambda_{reverse}$ | Average Absolute Value of $\lambda_{direct}-\lambda_{reverse}$ |
|---|---|---|---|---|---|---|---|
| 0..... | 100 | −0.002 A | 0.034 A | 4–5–6.... | 74 | +0.0015 A | 0.0232 A |
| 1..... | 100 | − .007 | .029 | 7–8–9–10. | 27 | + .0051 | .028 |
| 2..... | 84 | − .007 | .031 | >10..... | 8 | +0.011 | 0.0295 |
| 3..... | 100 | −0.0062 | 0.0272 | | | | |

MTW 1992—COMPARISON BETWEEN DIRECT AND REVERSE MEASUREMENTS

| Intensity | No. of Lines | Average Value of $\lambda_{direct}-\lambda_{reverse}$ | Average Absolute Value of $\lambda_{direct}-\lambda_{reverse}$ | Intensity | No. of Lines | Average Value of $\lambda_{direct}-\lambda_{reverse}$ | Average Absolute Value of $\lambda_{direct}-\lambda_{reverse}$ |
|---|---|---|---|---|---|---|---|
| 0..... | 100 | +0.0037 A | 0.0381 A | 3..... | 60 | −0.0122 A | 0.0287 A |
| 1..... | 100 | + .0055 | .0357 | 4–5–6.... | 36 | − .0164 | .0270 |
| 2..... | 100 | −0.0073 | 0.0317 | 7–8–9–10. | 10 | −0.0054 | 0.0172 |

velocity-curves is not the same: it is 30 km/sec for *Eu* II, 25 km/sec for *Dy* II and *Pr* II, 20 km/sec for *Ce* II and *Ni* I, 15 km/sec for *Sm* II, 10 km/sec for *Gd* II, and less than 5 km/sec for *Sr* II. The reality of this effect is attested by the small range shown by *Gd* II, of which there are many strong unblended lines.

*b*) Lines which show a remarkable double wave, with principal maximum at phase $5^d0$, secondary maximum at phase $2^d0$, principal minimum at phase $0^d7$, and secondary minimum at phase $3^d5$. This type of variation is best shown by *Cr* II, where the total range is 15 km/sec. It is conspicuously present for *Cr* I, where the range is even larger, though the scatter is also larger. The same type is shown by *Fe* II and *Fe* I, though the range is only 10 km/sec, and by *Mn* II, where the range is also about 10 km/sec. The variation of *Ti* II seems to be intermediate between types a and b. Considering the large number of excellent lines of *Ti* II used in forming this curve, the observed maximum velocity at phase 1.5 days probably reflects a superposition of the principal maximum of type a and the secondary maximum of type b.

*c*) Lines which show no variation. Conspicuous in this group is *Mg* II with a very small range, in spite of the fact that the curve is based upon one line only, λ 4481. Other representatives are *Si* II, *H*, and *Ca* II.

TABLE 7

WAVE-LENGTHS REGIONS MEASURED

| From λ | To λ | Plate | Phase | Combined Phases |
|---|---|---|---|---|
| 3407.315 | 3554.850 | MtW 2544 | 2.363 | |
| 3554.850 | 4673.278 | MtW 2544 | 2.363 | 3.042 |
| | | MtW 2540 | 3.721 | |
| 4673.278 | 4687.437 | MtW 2540 | 3.721 | |
| 3440.714 | 3758.242 | MtW 2543 | 1.323 | |
| 3758.242 | 4539.596 | MtW 2543 | 1.323 | 1.482 |
| | | MtW 1669 | 1.642 | |
| 4539.596 | 4601.279 | MtW 1669 | 1.642 | |
| 3606.724 | 3677.920 | MtW 2580 | 4.956 | |
| 3677.920 | 4724.272 | MtW 2580 | 4.956 | 5.003 |
| | | MtW 1992 | 5.050 | |
| 4724.272 | 4740.820 | MtW 1992 | 5.050 | |
| 3648.386 | 3920.619 | MtW 2229 | 4.460 | |
| 3920.619 | 4647.340 | MtW 2229 | 4.460 | 4.490 |
| | | Cd 81 | 4.520 | |
| 4647.340 | 4673.344 | Cd 81 | 4.520 | |
| 3677.677 | 3760.841 | MtW 1995 | 0.691 | |
| 3760.841 | 4677.144 | MtW 1995 | 0.691 | 0.756 |
| | | MtW 1667 | 0.822 | |
| 4677.144 | 4740.785 | MtW 1995 | 0.691 | |

TABLE 8

| Diff. in Exc. Pot.* | Ratio $\left(\frac{I_1}{I_2}\right)_{arc} / \left(\frac{I_1}{I_2}\right)_{\alpha^2 CVn}$ | Diff. in Exc. Pot.* | Ratio $\left(\frac{I_1}{I_2}\right)_{arc} / \left(\frac{I_1}{I_2}\right)_{\alpha^2 CVn}$ |
|---|---|---|---|
| 1 volt | 0.31 | 4 volt | 0.010 |
| 2 | 0.10 | 5 | 0.003 |
| 3 | 0.031 | | |

* Two lines of same spectral region.

Attention may be drawn to the fact that some of the curves are systematically displaced from one another. *H* and *Si* II cluster around 0 km/sec; *Mg* II gives, in the mean, about −9 km/sec, while *Sr* II gives +7 km/sec. These differences are much too large to be caused by errors of measurement. They may be attributable to blends; but in the case of *Mg* II no blend is known that would be strong enough to produce the observed displacement, while in the case of *Sr* II a weak line of *Cr* II may possibly influence the measured wave length to a slight extent. It is entirely possible, though by no means certain, that we are dealing here with an effect of relative motion similar to that observed by Adams in several other stars.

TABLE 9

OBSERVED INTENSITIES OF *Ce* III LINES

| λ | Lab. Int. | Phase | | | | | | | Blends | Spec. Not. |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Coudé | | *CQ* | | | | | | |
| | | 0.823 | 1.863 | 0.47 | 1.46 | 2.93 | 3.94 | 4.93 | | |
| 3353.26 | 150 | ..... | ..... | 3 | 4 | ..... | ..... | 4 | *Cr* II | $fs^3F^0_4-fp^3F_4$ |
| 3395.73 | 50 | ..... | ..... | 1–2 | 1–2 | 3 | 2 | 1 | *Cr* II, *Fe* II | $fs^1F^0_3-fp^3F_4$ |
| 3427.332 | 125 | ..... | 1n (bl) | 2 | 1 | 1 | 2 | 2 | Weak *Eu* II, *Cr* II, *Fe* I | $fs^3F^0_2-fp^3F_2$ |
| 3443.609 | 150 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | Weak *Nd* II, *Zr* II | $fs^3F^0_2-fp^3G_3$ |
| 3454.368 | 150 | 0 | 2 | 2 | 2 | 1n | 2n | 2–3 | Very weak *Nd* II + *Dy* II | $fs^3F^0_3-fp^3F_2$ |
| 3459.374 | 200 | 2 | 3 | 3 | 2 | 1–2 | 2 | 3 | *Cr* II | $fs^3F^0_4-fp^1F_3$ |
| 3470.894 | 300 | 0 | 2 | 1+ | 1n | 1 | 1–2 | 2 | Very weak *Nd* II + *Dy* II | $fs^3F^0_3-fp^3G_3$ |
| 3497.755 | 60 | 4 bl | 4 bl | 3 | 3–4 | 2 | 3 | 3 | *Fe* II, *Fe* I, *Zr* II, *Dy* II | $fs^3F^0_4-d^2\,^1G_4$ |
| 3504.596 | 100 | 4nn | (5n) bl | 3 | 2+ | 2 | 3 | 3+ | *Ti* II (*Dy* II strong line) (should decrease) | $fs^1F^0_3-fp^1F_3$ |
| 3543.999 | 80 | 1 | 1 | 1 | 1 | ? | 1–0 | 2 | Weak *Eu* II, *Dy* II | $fs^1F^0_3-d^2\,^1G_4$ |

It will be noticed that in a general way our groups a, b, and c coincide with the groups A, B, and C first established by Belopolsky, which represent lines varying in intensity, like *Eu* II; lines varying in the opposite sense, like *Cr* II; and lines which remain constant in intensity, like *Mg* II. There are appreciable differences in the results of different observers who have attempted to classify the lines into groups A, B, and C. For example, Belopolsky considers *H*, *Mg* II, *Ca* II, and *Fe* II to belong to class C. Tai attributes *Fe* II to group B and *Fe* I to group A, while for *H*, *Mg* II, and *Si* II the group may be either B or C. But it is undoubtedly significant that all rare earths belong simultaneously to groups A and a, while *Cr* II, the most conspicuous representative of group B, is also the most characteristic representative of group b.

Although it was not the primary purpose of this investigation to provide extensive data concerning the variations in the intensities, we have estimated on an arbitrary scale the intensities of a number of lines of different elements, in order to verify Tai's conclusion that the rare earths all belong to group A. These estimates are independent of those made during the measurements. Their advantage consists in the fact that they were made by comparing the enlargements of three McDonald coudé spectrograms, Cd 77, Cd 81, and Cd 86. The corresponding phases are $3^d530$, $4^d520$, and $5^d430$. The estimates in Table 10 are given in this order. The last phase is, of course, very close to

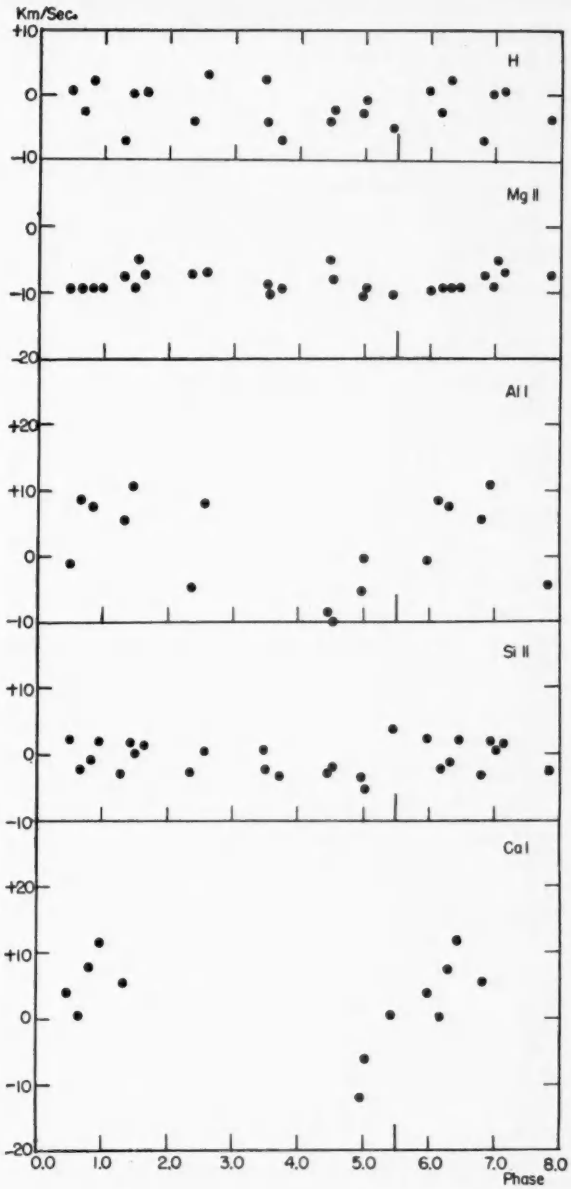
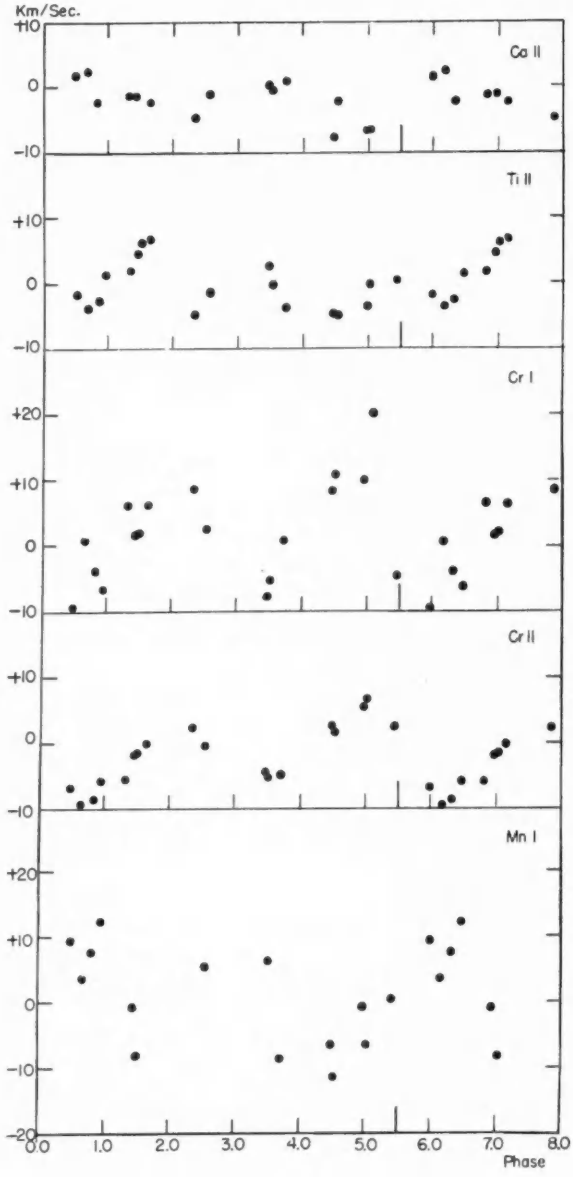



FIG. 1.—Radial velocities of $\alpha^2$ Canum Venaticorum


Km/Sec.
+10
0
−10
Ca II
Ti II
+20
Cr I
Cr II
Mn I
−20
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
Phase

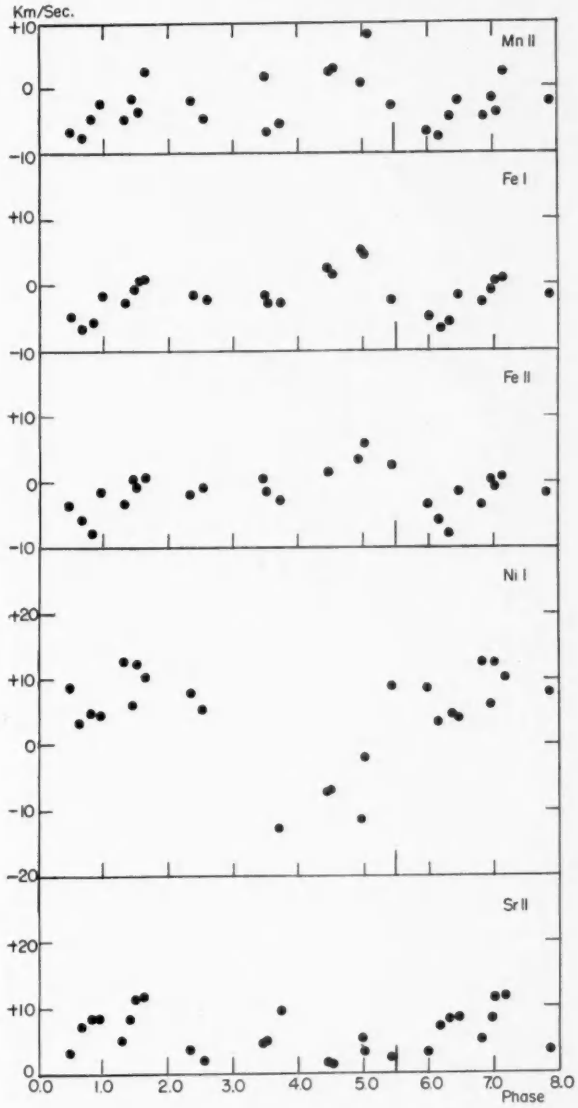



FIG. 3.—Radial velocities of $\alpha^2$ Canum Venaticorum

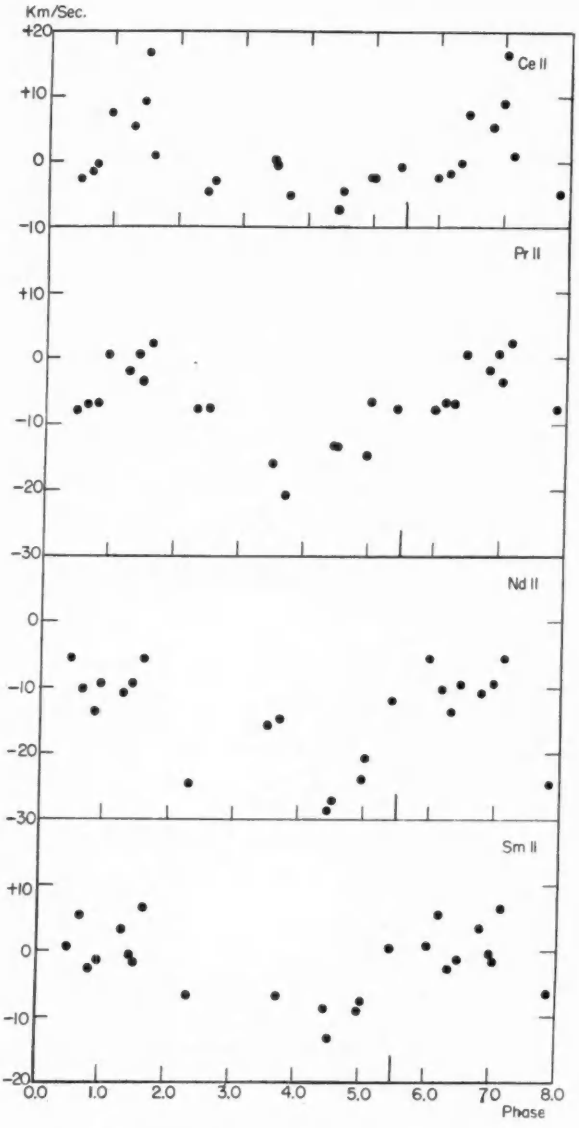



FIG. 4.—Radial velocities of $\alpha^2$ Canum Venaticorum

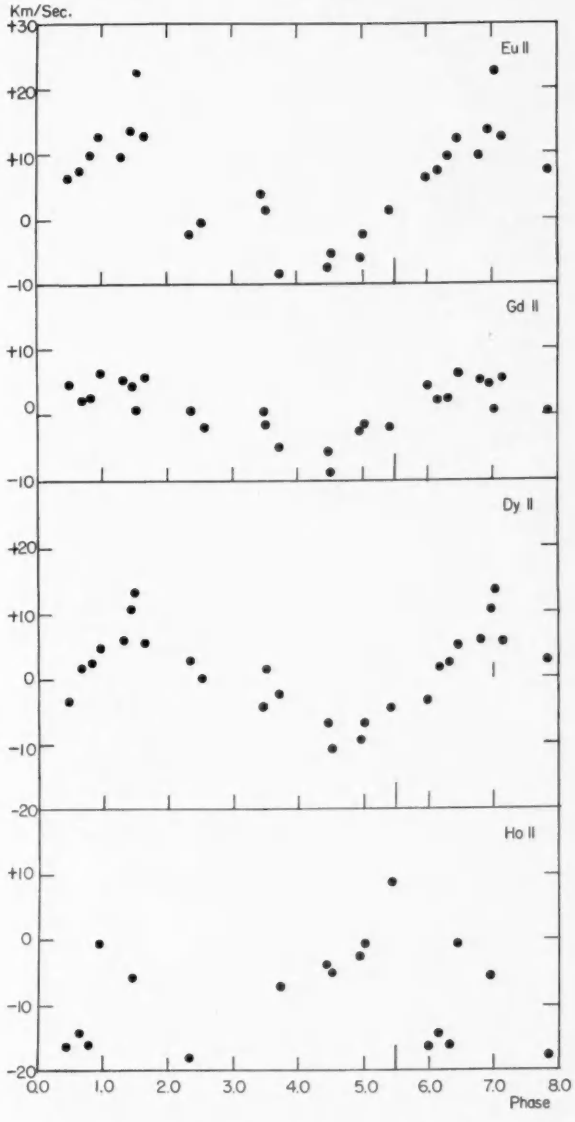



FIG. 5.—Radial velocities of $\alpha^2$ Canum Venaticorum

TABLE 10

ESTIMATES OF LINE INTENSITIES

| Line | Phases | | | Line | Phases | | |
|---|---|---|---|---|---|---|---|
| | 3.530 | 4.520 | 5.430 | | 3.530 | 4.520 | 5.430 |
| | *Si* II (14) | 16.3 v. | (C) | | *Fe* II (26) | 16.5 v. | (B-C) |
| 4128.0 | 6 | 6 | 6 | 4057.5 | 3 | 3 | 3 |
| | | | | 4061.8 | 3 | 4 | 4 |
| | | | | 4122.6 | 4 | 4 | 3 |
| | *Ti* II (22) | 13.6 v | (A) | 4233.2 | 8 | 6 | 5 |
| | | | | 4385.4 | 5 | 4 | 3 |
| | | | | 4461.6 | 3 | 4 | 2 |
| 4163.6 | 1 | 4 | 4 | 4489.2 | 5 | 6 | 4 |
| 4171.9 | 4 | 4 | 5 | | | | |
| 4300.0 | 0 | 4 | 5 | | | | |
| 4301.9 | 0 | 3 | 4 | | *Ni* I (28) | 7.6 v. | (A) |
| 4312.8 | 2 | 3 | 4 | | | | |
| 4314.9 | 2 | 3 | 3 | | | | |
| 4386.8 | 2 | 4 | 5 | 4401.6 | 0 | 3 | 5 |
| 4395.0 | 2 | 4 | 5 | | | | |
| 4395.8 | 2 | 3 | 3 | | | | |
| 4468.5 | 2 | 3 | 3 | | *Sr* II (38) | 11.0 v. | (A) |
| 4488.3 | 1 | 3 | 3 | | | | |
| 4501.3 | 2 | 3 | 3 | 4077.7 | 3 | 6 | 5 |
| | *Cr* I (24) | 6.7 v. | (C–A) | | | | |
| | | | | | *Ce* II (58) | | (A) |
| 4254.4 | 2 | 3 | 2 | | | | |
| | | | | 4117.0 | 1 | 3 | 3 |
| | | | | 4186.6 | 0 | 2 | 1 |
| | *Cr* II (24) | 16.6 v. | (B) | 4255.8 | 1 | 3 | 1 |
| | | | | 4289.9 | 0 | 5 | 6 |
| | | | | 4418.8 | 1 | 3 | 2 |
| 4052.0 | 5 | 3 | 0 | 4461.1 | 1 | 3 | 4 |
| 4070.9 | 2 | 3 | 1 | 4486.9 | 0 | 2 | 1 |
| 4076.9 | 5 | 6 | 3 | | | | |
| 4195.4 | 3 | 3 | 1 | | | | |
| 4242.4 | 5 | 5 | 3 | | *Pr* II (59) | | (A) |
| 4269.3 | 3 | 3 | 2 | | | | |
| | | | | 4032.9 | 0 | 3 | 3 |
| | *Mn* II (25) | 15.7 v. | (A) | | | | |
| | | | | | *Nd* II (60) | | (A) |
| 4136.9 | 1 | 3 | 2 | | | | |
| 4259.3 | 2 | 3 | 3 | | | | |
| | | | | 4075.1 | 0 | 0 | 3 |
| | | | | 4177.3 | 0 | 0 | 2 |
| | *Fe* I (26) | 7.8 v. | (A) | | | | |
| | | | | | *Sm* II (62) | 11.4 v. | (A) |
| 4260.5 | 1 | 3 | 2 | | | | |
| 4271.8 | 2 | 3 | 3 | | | | |
| 4307.9 | 2 | 3 | 3 | 4434.3 | 2 | 3 | 4 |
| 4404.8 | 4 | 5 | 6 | 4452.7 | 0 | 1 | 3 |

TABLE 10—*Continued*

| Line | Phases | | | Line | Phases | | |
|---|---|---|---|---|---|---|---|
| | 3.530 | 4.520 | 5.430 | | 3.530 | 4.520 | 5.430 |
| | *Eu* II (63) | 11.2 v. | (A) | | *Gd* II (64) | | (A) |
| 4085.4 | 0 | 3 | 3 | 4184.2 | 1 | 3 | 4 |
| 4129.7 | 0 | 8 | 10 | 4212.0 | 0 | 5 | 5 |
| 4205.0 | 0 | 4 | 10 | 4215.0 | 1 | 3 | 4 |
| 4270.5 | 0 | 1 | 3 | 4217.2 | 1 | 3 | 4 |
| 4355.1 | 0 | 3 | 6 | 4241.3 | 0 | 2 | 3 |
| 4414.6 | 0 | 1 | 3 | 4251.7 | 1 | 3 | 5 |
| 4435.6 | 2 | 5 | 6 | 4467.2 | 0 | 2 | 3 |
| | | | | 4483.3 | 0 | 3 | 5 |
| | *Gd* II (64) | | (A) | | *Dy* II (66) | | (A) |
| 4037.3 | 1 | 5 | 3 | | | | |
| 4049.9 | 0 | 3 | 2 | 4036.3 | 0 | 2 | 5 |
| 4053.3 | 1 | 3 | 5 | 4050.6 | 0 | 3 | 5 |
| 4078.4 | 1 | 4 | 3 | 4143.1 | 1 | 2 | 5 |
| 4130.4 | 0 | 2 | 1 | 4409.4 | 2 | 3 | 4 |

the predicted maximum of intensity of *Eu* II. The elements are arranged in order of atomic weight. The ionization potential and the intensity group are given at the head of each element. It is certain that all rare earths included in Table 10 belong to group A, and it is probable that the range in intensity is largest for *Eu* II, and somewhat smaller for *Gd* II. But this conclusion may be related to the fact that at maximum the lines of *Eu* II are the strongest among the rare-earth lines.

TABLE 11

| Phase in Days | Diffuseness of Lines | Phase in Days | Diffuseness of Lines |
|---|---|---|---|
| 5.050 | 4 | 2.363 | 10 |
| 0.691 | 3 | 3.721 | 8 |
| 0.822 | 1 | 4.460 | 2 |
| 1.323 | 3 | 4.956 | 5 |
| 1.642 | 2 | 5.050 | 4 |

It has already been pointed out[1] that the contours of the lines of groups C and B are somewhat broader when the *Eu* II lines are weak. Estimates of diffuseness were made on the Mount Wilson coudé plates for the region near *Ca* II K. If 10 designates the broadest lines and 1 the narrowest (on any arbitrary scale), we obtain the relation with phase shown in Table 11. The lines were broadest at phases 2.3 and 3.7 days. They were narrow at phase 0.8 and again at phase 4.5 days. Possibly the double wave shown in these estimates is related to the double wave in the radial velocities of group b and to the peculiar changes in line contours observed in $\epsilon$ Ursae Majoris.[8]

We are indebted to Mrs. Martha B. Carlson and Mrs. Gladys Rezek for much help in the computations, to Miss Alice Johnson for the reproductions of the spectrum, and to Miss J. Ringstad and Mrs. T. Belland for the typing of the tables reproduced by planographing.

[8] Struve and Hiltner, *Ap. J.*, **98**, 225, 1943.

# NOTES

## CONTRACTIVE EVOLUTION OF MASSIVE STARS

It is generally accepted that during the largest part of their evolution stars receive their energy supply through the so-called "carbon-nitrogen" (*C-N*) cycle, transforming *H* into *He*.[1] Combining the formula for the rate of thermonuclear reactions with the equilibrium equations of stellar structure, one can obtain in the frame of a radius-luminosity (*R-L*) diagram a line representing the position of stars of various masses. This "*C-N* sequence" passes through the sun, Sirius, V Puppis, and such luminous stars as 29 CMa and AO Cas. Since the ratio $L/M$ rapidly increases with the mass, heavier stars consume hydrogen at a much faster rate; it can be calculated that for the stars heavier than Sirius the duration of the hydrogen evolution becomes shorter than the estimated age of the stellar universe. Thus we must assume that the process of star formation is still continuing at present and that, on the other hand, there must exist a large number of massive stars which have already consumed their hydrogen and are in the stage of ultimate gravitational contraction.

It follows that the main sequence, which in its lower part coincides with the *C-N* sequence, must fan out for more luminous stars, being limited on the right by the *C-N* sequence and extending to the left to include the stars at various stages of contraction. We know, in fact, a large number of stars located in the *R-L* diagram considerably to the left from the *C-N* sequence; this includes P Cygni stars, Wolf-Rayet stars, and the nuclei of planetary nebulae. All these stars, with the possible exception of P Cygni stars, which are just off the *C-N* sequence, definitely receive their energy supply from the gravitational contraction.

In calculating the evolutionary track of a contracting star, it is important to keep in mind the fact that the opacity[2] law changes during the contraction. Whereas for all stars of the *C-N* sequence ($I_c$ = 20 to 40 · $10^6$ °C, and the densities below 100) we can safely use the expression $K \sim \rho^{0.5} T^{-2.75}$, the dependence of the opacity coefficient on the density and temperature becomes considerably less marked in the early stages of contraction (i.e., for increasing $\rho$ and $T$). Finally, when the contraction has progressed far enough to bring $\rho_c$ above $10^3$ gm/cm$^3$ and $T_c$ above $10^8$ °C, the value of $K$ becomes constant. In Figure 1 we give the expected evolutionary track of a star with the mass $10M\odot$, and with $\mu = 1.7$ (corresponding to the complete transformation of *H* into *He*) beginning with the position of the star in the *N-C* sequence. The horizontal part of the track corresponds to *K*-constant. The numerical value of the luminosity in this latter case is taken from the calculations of Keenan[3] and Henrich[4] (the limit of applicability of these calculations being marked approximately by a vertical bar on the curve).

It is interesting to notice that the data for the Wolf-Rayet component of HD 193576 obtained by Wilson[5] fit nicely on the curve. Since the energy liberation is purely gravitational, one can easily calculate the rate of contraction from the total luminosity; the radius of the star must decrease by a factor of 1.2 in $10^3$ years and by a factor 4 in $10^4$

[1] H. Bethe, *Phys. Rev.*, **55**, 434, 1939.

[2] Ph. M. Morse, *Ap. J.*, **92**, 27, 1940.

[3] *Ap. J.*, **89**, 499, 1939.

[4] *Ap. J.*, **98**, 192, 1943. The author is grateful to Dr. Henrich for communicating his results before publication.

[5] *Ap. J.*, **91**, 379, 1940.

years. Because of the constancy of total luminosity, the surface temperature of the star must increase as $R^{-\frac{1}{2}}$, and the energy emitted in the visible part of the spectrum must decrease as $R^{+\frac{3}{2}}$. Thus, in a thousand years the star must become visually fainter by 0.2 mag., and in ten thousand years by 2.5 mag. The actually observed luminosity changes may be somewhat different because of the change of wave length in the shell surrounding the star.

In comparing Wolf-Rayet stars with planetary nebulae, it must be remembered that both groups are known to eject their material as the result of high radiative pressure in their atmospheres. According to Aller,[6] radii, densities, and ejection velocities of typical Wolf-Rayet stars are given by $R \cong 10^{12}$ cm, $\rho \cong 10^{-12}$ gm/cm$^3$; $V \cong 2 \cdot 10^8$ cm/sec., with the total outgoing stream of matter equal to about $10^{21}$ gm/cm$^3$. If we assume that the ejected material continues to move with its original velocity, the shell around a Wolf-Rayet star must attain the diameter of an average planetary in less than 50 years. By this time the density of the shell will be $\cong 10^{-22}$ gm/cm$^3$, i.e., about 1 per cent of the observed densities in typical planetaries.

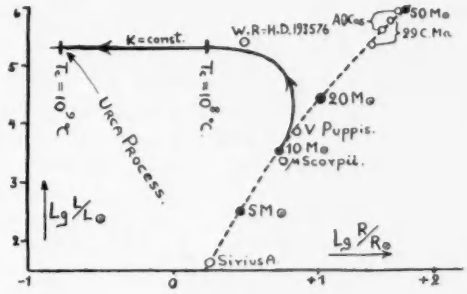



FIG. 1

Since none of the stars observed by Wolf and Rayet in 1867 has turned into anything like a faint planetary nebula, we must conclude that the matter ejected from Wolf-Rayet stars is slowed up by gravitational forces. This seems quite possible since the estimated escape velocity near the surface of these stars is comparable with the observed ejection velocity. Assuming that the ejected material is slowed down to only $2 \cdot 10^6$ cm/sec (this represents the actual expansion velocities observed in planetaries), we come to the density of $10^{-20}$ gm/cm$^3$ at the time when the diameters of planetaries are reached. This is in good accord with the estimated densities in typical planetaries. In order to expand to the size of a planetary, the slowed-down material from Wolf-Rayet stars would require between $10^3$ and $10^4$ years; and, as stated above, the central star will visually decrease during this time by several magnitudes.

It is known that planetary nuclei are actually fainter than Wolf-Rayet stars by several magnitudes, so that there seems to be no observational objection to the assumption that planetary nebulae represent the result of Wolf-Rayet evolution. The radii of planetary nuclei must be, in this case, about ten times smaller than the radii of Wolf-Rayet stars, and their central temperatures correspondingly ten times higher. Since for Wolf-Rayet stars $T_c \cong 10^8$ °C, we obtain for planetary nuclei $T_c \cong 10^9$ °C. Now it has been shown by the present writer and Schoenberg[7] that a temperature of this order represents the threshold for the so-called Urca processes, in which large quantities of neutrinos are being produced in the center of the star. The rapid cooling of the interior

[6] *Ap. J.*, **97**, 135, 1943.

[7] G. Gamow and M. Schoenberg, *Phys. Rev.*, **59**, 539, 1941; G. Gamow, *Phys. Rev.*, **59**, 617, 1941.

through the escape of high-energy neutrinos must inevitably cause a rapid collapse of the stellar body, observed as a violent supernova explosion. Thus it seems very probable that the nuclei of planetary nebulae represent the last stage of stellar evolution preceding such explosions. Let us hope that one of the planetaries will explode during our lifetime!

G. GAMOW

GEORGE WASHINGTON UNIVERSITY
WASHINGTON, D.C.
July 18, 1943

## ON WC AND WN STARS

It is well known that Wolf-Rayet stars can be divided into two groups: the WC group with strong carbon emission lines, and the WN group in which carbon is replaced by nitrogen. According to the recent investigations of L. H. Aller,[1] the atmospheres of WC stars contain about 2 per cent of carbon with a negligible amount of nitrogen, whereas in WN stars we find about 1.7 per cent of nitrogen and less than 0.2 per cent of carbon. (These values are obtained from Aller's values of $C/He$ and $N/He$ and the assumption that in these stars hydrogen is almost completely replaced by helium.) It seems that, whereas the observed intensity ratio of $C$ and $N$ lines must not necessarily correspond to the actual abundance ratio of these elements because of the different conditions of excitation and mass ejection, the change of this ratio from star to star indicates a real difference in chemical constitution. The variation in the relative amounts of $C$ and $N$ atoms (with the combined amount remaining seemingly constant) is of particular interest, since these two elements represent the main participants in the thermonuclear reaction cycle responsible for the energy production in the stars.[2] Since the nuclear reaction rates of $C$ and $N$ change differently with the interior temperature of the star, we should expect that the $N/C$ ratio would be different in stars of different masses and luminosities. From the ordinary formula for the rate of thermonuclear reactions[3] we find that the values of the $N/C$ ratio for different temperatures must be connected by the relation

$$\left(\frac{N}{C}\right)_{T_1} : \left(\frac{N}{C}\right)_{T_2} = e^{3\left(\frac{\pi^2 m e^4}{2\hbar^2 k}\right)^{1/3}(7^{2/3}-6^{2/3})\left(\frac{1}{T_1^{1/3}}-\frac{1}{T_2^{1/3}}\right)} .$$

We find from this relation that with the increase of central temperature from $2\cdot 10^7\,^\circ$C to $5\cdot 10^7\,^\circ$C the value of the $N/C$ ratio must drop by a factor of 10. Thus, more massive, and consequently more luminous, stars must show a considerable preponderance of carbon, as compared with nitrogen. This seems to be in very good accord with the observed fact that WC stars are, on the average, brighter than WN stars.[4]

For the stars built on the ordinary point-source model with Cowling's convective core, the changes of the $N/C$ ratio taking place near the center would not be expected to affect the constitution of the outer layers because of the extremely low diffusion velocity through the radiative envelope. We must remember, however, that at the later stages of stellar evolution we may expect the formation of an energy-producing shell with a steadily increasing radius.[5] In their recent calculations of shell models S. Chandrasekhar

[1] *Ap. J.*, **97**, 135, 1943.

[2] H. Bethe, *Phys. Rev.*, **55**, 434, 1939.

[3] G. Gamow and E. Teller, *Phys. Rev.*, **53**, 608, 1938.

[4] B. Vorontsov-Velyaminov, *Zs. f. Ap.*, **8**, 195, 1934.

[5] G. Gamow and Charles Critchfield, *Ap. J.*, **89**, 244, 1939.

and L. R. Henrich[6] and Chandrasekhar and M. Schoenberg[7] arrived at the conclusion that the growth of such a shell must be stopped at comparatively early stages, because of the mathematical impossibility of joining the isothermal polytrope solution with a radiative equilibrium solution for the larger values of the shell radii. It seems, however, rather difficult to understand how this difficulty can stop the physical process of nuclear transformations in the stellar interior; and it may be suggested, as a possible way out of the difficulty, that in the stars with extended energy-producing shells, the energy transport through the outer envelope is accomplished not by the radiative flow but rather by powerful convective currents between the energy-producing shell and the photosphere of the stars. The assumption of such currents would also help to understand the parallelism between the chemical constitution of the Wolf-Rayet atmospheres and that of the energy-producing region.

G. GAMOW

GEORGE WASHINGTON UNIVERSITY
August 16, 1943

## ON THE LIFETIME OF CLUSTERS OF EXTRAGALACTIC NEBULAE

ABSTRACT

The theory of dynamical friction, previously applied to clusters of stars, is now applied to clusters of extragalactic nebulae. Times of relaxation of the order of $10^9$–$10^{10}$ years are found. These imply $10^{11}$–$10^{12}$ years as an upper limit to the time scale of the universe.

The theory of dynamical friction developed by Chandrasekhar having been applied to star clusters, it appears that we might next consider its application to clusters of nebulae. This is the object of this note.

As in star clusters, an important factor in the evolution of clusters of nebulae must be their gradual impoverishment due to the escape of their members. This escape of members results from the fluctuating gravitational field acting on a nebula, giving rise to a finite probability for a nebula to acquire a velocity sufficient to escape from the cluster during any specified length of time $t$. Having acquired this necessary velocity, the nebula will escape from the cluster. Following the theory presented by Chandrasekhar in his papers on dynamical friction,[1] we shall now evaluate the half-lives of two clusters of nebulae—the Virgo and Coma clusters—for which we appear to have fairly reliable data.

In our calculations we shall ignore the effect of the velocities of recession, associated with an expanding universe, and consider the clusters simply as composed of $n$ mutually attracting mass points. Assuming them to be in statistically steady states, we have for the root mean square velocity of the cluster nebulae

$$\overline{v^2} = \frac{1}{2}\frac{GM}{\overline{R}}, \qquad (1)^2$$

where $G$ is the constant of gravitation, $M$ the total mass of the cluster, and $\overline{R}$ its average radius. Expressing the mass and the radius in units of $10^{11}$ solar masses and $10^6$ parsecs, respectively, we obtain

$$\sqrt{\overline{v^2}} = 14.6\sqrt{\frac{\overline{\mathcal{M}}}{\overline{R}}}\ \text{km/sec}. \qquad (2)$$

The radius being known observationally to greater accuracy, we shall set up tables of the predicted dispersions of the velocities in the clusters for relevant ranges of the

[6] *Ap. J.*, **94**, 525, 1941.

[7] *Ap. J.*, **96**, 161, 1942.

[1] *Ap. J.*, **97**, 255, 263, and **98**, 54, 1943.

[2] S. Chandrasekhar, *Principles of Stellar Dynamics*, p. 200, University of Chicago Press, 1942.

total mass. For the Virgo cluster, the radius of which is $2 \times 10^5$ parsecs,[3] we find the values given in Table 1. The value of greatest interest is that which corresponds to a mean mass of $2 \times 10^{11}$ solar masses[3] for a single nebula and a total number of 500 nebulae[3] in the cluster (i.e., $\mathcal{M} = 1000$). We can compare this value of 1040 km/sec

TABLE 1

THE PREDICTED DISPERSION OF THE VELOCITIES IN THE VIRGO CLUSTER

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| $\mathcal{M}$ | 50 | 250 | 400 | 500 | 600 | 800 | 1000 | 1200 |
| $\sqrt{\overline{v^2}}$ | 232 | 518 | 655 | 732 | 802 | 926 | 1040 | 1130 |

with that obtained from the observationally determined dispersion of the radial velocities, of the order of 600–650 km/sec,[3,4] by the relation

$$(\overline{v^2})^{1/2} = (3\overline{v_r^2})^{1/2} \cong 1040\text{–}1130 \text{ km/sec} . \tag{3}$$

The predicted and observed dispersions of the peculiar velocities are seen to be in good agreement.

For the Coma cluster, the radius of which is $6.5 \times 10^5$ parsecs,[5] Table 2 is obtained. Assuming one to two thousand nebulae in the cluster, the average mass of each being of the order of $2 \times 10^{11}$ solar masses, we find velocities about one-half the value, 2100 km/sec,[5] determined from observations. This discrepancy between the predicted and the observed dispersions may possibly be attributed to the effect of the velocities of recession, this effect increasing with the radii of the clusters.

TABLE 2

THE PREDICTED DISPERSION OF THE VELOCITIES IN THE COMA CLUSTER

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $\mathcal{M}$ | 200 | 400 | 800 | 1200 | 1600 | 2000 | 2400 | 2800 | 3200 | 3600 | 4000 |
| $\sqrt{\overline{v^2}}$ | 257 | 364 | 514 | 630 | 727 | 813 | 890 | 962 | 1030 | 1090 | 1150 |

Using these values for the dispersions of the peculiar velocities, we have next to determine the time of relaxation for each cluster, the time required for the setting-up of a Maxwellian distribution of velocities in each system. The time of relaxation can be most conveniently defined by $\eta_0^{-1}$, where

$$\eta_0 = 8\pi N m^2 G^2 \left(\log_e \left[\frac{D_0 |\overline{v}|^2}{2GM}\right]\right)\left(\frac{3}{2|\overline{v}|^2}\right)^{3/2} \frac{4}{3\sqrt{\pi}} , \tag{4}[6]$$

$N$ denoting the number of nebulae per unit volume, $m$ their average mass, and $D_0$ the average distance between them. The quantity $\eta_0$, defined as in equation (4), is the coefficient of dynamical friction in the limit of zero velocity. Introducing the substitutions indicated on page 202 of Chandrasekhar's *Principles of Stellar Dynamics*, we obtain

$$\frac{1}{\eta_0} = 13.1 \times 10^8 \sqrt{\frac{n\overline{\mathcal{R}}^3}{m}} \frac{1}{\log_{10} n - 0.45} \text{ years} , \tag{5}$$

where now $m$ and $\overline{\mathcal{R}}$ are expressed in units of $10^{11}$ solar masses and $10^6$ parsecs, respectively. Tables 3 and 4 give values of this time of relaxation for the two clusters,

[3] S. Smith, *Ap. J.*, **83**, 23, 1936.

[4] M. Humason, *Ap. J.*, **83**, 10, 1936.

[5] F. Zwicky, *Ap. J.*, **95**, 555, 1942.

[6] S. Chandrasekhar, *Ap. J.*, **98**, 55 (eq. [10]), 1943.

over relevant ranges of $n$ and $m$. Their times of relaxation being of the order of $10^9$–$10^{10}$ years, we shall now proceed to determine the half-lives of such clusters.

The expectation that an average nebula will have acquired the necessary velocity for escape during a time $\tau$ (in units of $\eta_0^{-1}$) $\gtrsim 5$ is given by

$$Q(\tau) = 1 - e^{-\lambda_1 \tau} \qquad (\tau = \eta_0 t), \tag{6}$$ [7]

the expression $1/\lambda_1\eta_0$ being regarded, therefore, as a measure of the half-life of a cluster. For a root mean square velocity of escape equal to twice the mean square velocity of the

TABLE 3

THE TIME OF RELAXATION FOR THE VIRGO CLUSTER

| $n$ | $m$ | | |
|---|---|---|---|
| | $\frac{1}{2}$ | 1 | 2 |
| 400 | $1.5\times10^9$ | $1.1\times10^9$ | $7.7\times10^8$ |
| 500 | $1.6\times10^9$ | $1.17\times10^9$ | $8.2\times10^8$ |
| 600 | $1.7\times10^9$ | $1.23\times10^9$ | $8.7\times10^8$ |

TABLE 4

THE TIME OF RELAXATION FOR THE COMA CLUSTER

| $n$ | $m$ | | |
|---|---|---|---|
| | $\frac{1}{2}$ | 1 | 2 |
| 800 | $1.1\times10^{10}$ | $7.9\times10^9$ | $5.6\times10^9$ |
| 1000 | $1.2\times10^{10}$ | $8.5\times10^9$ | $6.0\times10^9$ |
| 1200 | $1.28\times10^{10}$ | $9.0\times10^9$ | $6.4\times10^9$ |
| 1400 | $1.34\times10^{10}$ | $9.5\times10^9$ | $6.7\times10^9$ |
| 1600 | $1.4\times10^{10}$ | $9.95\times10^9$ | $7.0\times10^9$ |
| 1800 | $1.47\times10^{10}$ | $1.0\times10^{10}$ | $7.3\times10^9$ |
| 2000 | $1.52\times10^{10}$ | $1.1\times10^{10}$ | $7.6\times10^9$ |

nebulae in the cluster,[8] the value of $\lambda_1$ is found to be 0.0075. The half-life of the cluster may then be written as

$$\text{Half-life of the cluster} = 133\,\eta_0^{-1}. \tag{7}$$ [9]

Introducing our previously determined values of $\eta_0^{-1}$, we find half-lives of the order of $10^{11}$–$10^{12}$ years for clusters of nebulae.

On the basis of the above calculations (the effect of an expanding universe being neglected), $10^{11}$–$10^{12}$ years may be regarded as an upper limit to the time scale of the universe.

In conclusion I should like to express my great indebtedness to Dr. S. Chandrasekhar for his constant guidance.

MERLE TUBERG

YERKES OBSERVATORY
August 11, 1943

[7] *Ibid.*, p. 59 (eq. [46]).

[8] S. Chandrasekhar, *Principles of Stellar Dynamics*, p. 206.

[9] S. Chandrasekhar, *Ap. J.*, **98**, 60 (eq. [48]), 1943.

## THE SPECTRUM VARIABLE 73 DRACONIS

ABSTRACT

The *Eu* II line, λ 4205, in 73 Draconis varies in intensity with a period of 20.27 days. Certain lines of *Ca* II, *Ti* II, and *Sr* II vary in phase with *Eu* II. Several lines of *Fe* II, *Fe* I, *Cr* II, *Si* II, and *Mg* II were examined, but they showed no variation. Eight of the best plates were measured, but no evidence was found of a real variation in radial velocity in connection with variations of intensity.

The spectrum of 73 Draconis was investigated in 1932 by W. W. Morgan.[1] From a series of 28 plates he determined the wave lengths and identifications of 477 lines. The

TABLE 1*

ESTIMATED INTENSITIES OF *Eu* II 4205 IN 73 DRACONIS

| Date | Julian Day | Int. | Phase (Days) | Date | Julian Day | Int. | Phase (Days) |
|---|---|---|---|---|---|---|---|
| 1941 | 2430000+ | | | 1942 | 2430000+ | | |
| Nov. 18.01 | 316.51 | 3.0 | 3.15 | Oct. 19.18 | 651.68 | 2.0 | 14.00 |
| 19.00 | 317.50 | 2.5 | 4.14 | Nov. 6.07 | 669.57 | 1.5 | 11.62 |
| Dec. 6.08 | 334.58 | 5.0 | 0.95 | 12.99 | 676.49 | 4.5 | 18.54 |
| 11.01 | 339.51 | 2.0 | 5.88 | 14.00 | 677.50 | 5.0 | 19.55 |
| 14.07 | 342.57 | 2.0 | 8.94 | 18.16 | 681.66 | 3.5 | 3.44 |
| 14.98 | 343.48 | 1.5 | 9.85 | 27.05 | 690.55 | 2.0 | 12.33 |
| 20.19 | 348.69 | 3.0 | 15.06 | Dec. 3.98 | 697.48 | 5.0 | 19.26 |
| 1942 | | | | 4.99 | 698.49 | 4.5 | 0.00 |
| Jan. 4.99 | 364.49 | 1.5 | 10.59 | 11.99 | 705.49 | 1.0 | 7.00 |
| 13.05 | 372.55 | 5.0 | 18.65 | 1943 | | | |
| 14.49 | 373.99 | 5.0 | 20.09 | Feb. 16.49 | 771.99 | 1.5 | 12.69 |
| Mar. 19.41 | 437.91 | 3.0 | 2.93 | 25.50 | 781.00 | 5.0 | 1.43 |
| Apr. 14.41 | 463.91 | 2.5 | 8.66 | Mar. 21.43 | 804.93 | 2.0 | 5.09 |
| 15.36 | 464.86 | 1.0 | 9.61 | 30.34 | 813.84 | 3.0 | 14.00 |
| May 10.41 | 489.91 | 2.0 | 14.39 | Apr. 1.38 | 815.88 | 4.0 | 16.04 |
| June 30.33 | 540.83 | 2.5 | 4.50 | 15.43 | 829.93 | 1.0 | 9.82 |
| July 2.38 | 542.88 | 1.0 | 6.55 | 21.37 | 835.87 | 4.0 | 15.76 |
| 3.14 | 543.64 | 1.5 | 7.31 | 22.33 | 836.83 | 3.0 | 16.72 |
| 12.26 | 552.76 | 5.0 | 16.43 | May 1.32 | 845.82 | 1.5 | 5.44 |
| 27.21 | 567.71 | 1.5 | 11.11 | 28.25 | 872.75 | 1.5 | 12.10 |
| Aug. 7.22 | 578.72 | 5.0 | 1.85 | June 11.18 | 886.68 | 1.5 | 5.76 |
| 11.37 | 582.87 | 3.0 | 6.00 | 23.31 | 898.81 | 4.0 | 17.89 |
| 25.29 | 596.79 | 4.5 | 19.92 | July 22.16 | 927.66 | 2.0 | 6.20 |
| Sept. 1.15 | 603.65 | 2.5 | 6.51 | 22.21 | 927.71 | 2.0 | 6.25 |
| 15.10 | 617.60 | 5.0 | 0.19 | 27.12 | 932.62 | 2.0 | 11.16 |
| 16.06 | 618.56 | 5.0 | 1.15 | 27.18 | 932.68 | 2.0 | 11.22 |
| 17.06 | 619.56 | 4.0 | 2.15 | 28.31 | 933.81 | 2.0 | 12.35 |
| 25.18 | 627.68 | 2.0 | 10.27 | Aug. 10.09 | 946.59 | 3.0 | 4.86 |
| 27.17 | 629.67 | 1.5 | 12.26 | 11.15 | 947.65 | 3.0 | 5.92 |
| 28.28 | 630.78 | 1.5 | 13.37 | 17.18 | 953.68 | 1.0 | 11.95 |
| Oct. 6.02 | 638.52 | 4.5 | 0.84 | 18.12 | 954.62 | 1.0 | 12.89 |
| 7.02 | 639.52 | 4.5 | 1.84 | 24.26 | 960.76 | 5.0 | 19.03 |
| 8.02 | 640.52 | 3.5 | 2.84 | | | | |

*The observers who participated and the number of plates taken by each are as follows: O. Struve (22), R. Williamson (16), C. A. Bauer (9), J. L. Greenstein (5), G. Hall (5), Mrs. M. Krogdahl (3), J. W. Swensson (2), and G. Münch (1).

variation of intensity of the *Eu* II line, λ 4205, had been previously announced by him,[2] and a special study of that line and three others—*Fe* II–*Ti* 4549, *Ti* II 4501, and *Ti* II 4571—revealed a period of about 20.7 days in the intensity.

[1] *Ap. J.*, **77**, 77, 1933. The star 73 Draconis is BS 7879 ($\alpha = 20^h32^m8$; $\delta = +74° 37'$ [1900]; mag., 5.2; Sp., A2p).

[2] *Ibid.*, **76**, 315, 1932.

Between November, 1941, and August, 1943, a new series of spectrograms was made with the one-prism spectrograph of the Yerkes Observatory. It seemed profitable at this time to re-examine the variations of intensity of certain lines and attempt to improve the period.

Table 1 gives the estimated intensities of the *Eu* II line, λ 4205, on an arbitrary scale of five steps. An intensity of 1 means that the line was barely distinguishable or only suspected. An estimate of 5 indicates maximum intensity. Three independent measures of the intensities were made and the averages taken.

Average intensities were plotted against time on a fairly large scale. Investigation showed that Morgan's period of 20.7 days was slightly too long. A period of 20.27 days seemed to fit the new observations satisfactorily and also connected them directly with his epoch, JD 2426908.0. Using JD 2430678.22 as a new phase zero, the phase for each plate was determined; and the resulting variation is shown in Figure 1. The ordinates

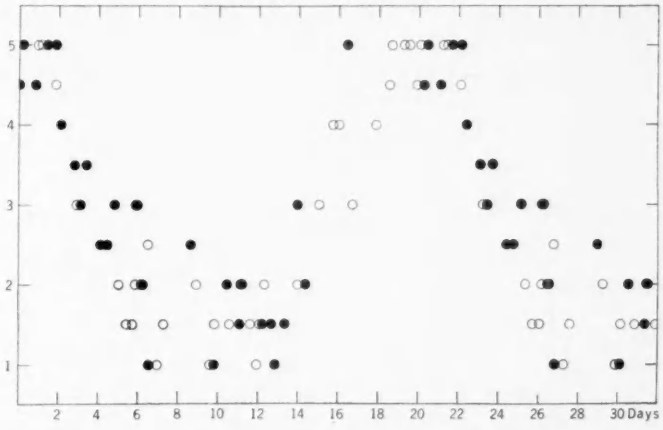



FIG. 1.—Intensity estimates of *Eu* II 4205 in the Spectrum of 73 Draconis

are arbitrary units of intensity; the abscissae are days. The more reliable measures from the better spectrograms are represented by open circles. Morgan's mean curve of variation showed minima broader than maxima, and the present plot confirms this. The two curves also agree in showing evidence of a slow increase to maximum, followed by a slightly more rapid decrease.

A study was made of variations in intensity of several other elments by examining 15 of the best plates corresponding to maximum or minimum for *Eu* II. The results are given in Table 2. Certain lines of *Ca* II, *Ti* II, and *Sr* II showed definite variations in phase with *Eu* II and apparently having the same period. The only disagreement with Morgan's work is concerning the line *Sr* II 4215, which he found to be at maximum when *Eu* II was at minimum.

The star 73 Draconis is an A2 dwarf and is similar to $\alpha^2$ Canum Venaticorum with respect to variable lines. In view of the fact that certain lines which vary in intensity in the latter star are known to vary also in radial velocity, a number of the best plates at maximum and minimum were selected for measurement. Eight star lines and 8 comparison lines were measured on each plate. Seven of the star lines were of constant intensity, while one was the variable *Eu* II line at λ 4205. The radial velocities computed from these measures and reduced to the sun are given in Table 3. Column A gives the average radial velocity of the 7 lines of constant intensity, while column B is for the single variable line λ 4205. Both average radial velocities A and B on the minimum plates are higher than on the maximum plates, but the difference is partly due to the

unusually large value obtained from the plate of November 6, 1942. One of the lines of constant intensity used was the *Fe* II–*Cr* II line at λ 4179. The velocities computed from this line ran consistently high and increased the averages by nearly 3 km/sec. Without this line the average would agree very well with the value of 10.2 km/sec, the average radial velocity of 73 Draconis as given by Campbell.[3]

TABLE 2

| Element | Lines Examined | Conclusion | Element | Lines Examined | Conclusion |
|---|---|---|---|---|---|
| *Fe* II | 4520, 4522 | Not variable | *Si* II | 4131 | Not variable |
| *Fe* I | 4673 | Not variable | *Mg* II | 4481 | Not variable |
| *Cr* II | 4242, 4261, 4269, 4555, 4558, 4588, 4634 | Not variable | *Ca* II | 3933 | Varies with *Eu* II |
| | | | *Ti* II | 4501, 4571 | Varies with *Eu* II |
| | | | *Sr* II | 4077, 4215 | Varies with *Eu* II |

TABLE 3

RADIAL VELOCITIES OF 73 DRACONIS

| *Eu* II AT MAXIMUM | | | *Eu* II AT MINIMUM | | |
|---|---|---|---|---|---|
| Date | Radial Velocity (Km/Sec) | | Date | Radial Velocity (Km/Sec) | |
| | A | B | | A | B |
| 1941, Dec. 6 | + 9.4 | +12.3 | 1942, Jan. 4 | +11.3 | + 9.2 |
| 1942, Jan. 13 | 11.9 | 6.2 | Nov. 6 | 23.3 | 16.4 |
| Nov. 14 | 15.3 | 9.1 | Dec. 11 | 15.7 | 16.6 |
| 1943, Aug. 24 | +16.7 | + 8.6 | 1943, Aug. 17 | +13.8 | + 4.6 |
| Av. | +13.3 | + 9.0 | Av. | +16.0 | +11.7 |

The average radial velocity for the one variable line, λ 4205, is less than the average for the constant lines on both maximum and minimum plates; but the difference in both cases is the same, 4.3 km/sec. This indicates that there is no evidence of variation in radial velocity in connection with variations of intensity.

This study was undertaken at the suggestion of Dr. Otto Struve. I am indebted to him and to Dr. G. Van Biesbroeck for assistance.

GENEVA E. DURHAM

YERKES OBSERVATORY
September 17, 1943

[3] *Lick Obs. Pub.*, **16**, 302, 1928.

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